University of Alberta

ATTENTIONAL EFFECTS OF GAZE DIRECTION

by

Christine Kelland Friesen ©

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in partial fulfillment of the requirements for the degree of

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This dissertation is dedicated with boundless love and gratitude to my husband Brad Friesen, to our son Chance, and to our daughter Olwen, whose support and many sacrifices over the years have made it possible for me to pursue my research interests. And also to my parents Barbara and David Kelland, for their encouragement (and forbearance) during my earlier school years.

Abstract

In a series of five studies (seven experiments), attentional cuing methods were employed to investigate the effects of perceived gaze direction. The first study reports that adults shifted their attention automatically to a location gazed at by a centrally presented schematic face -- even though the face's gaze direction did not predict where a target would occur. Like exogenous orienting to peripheral onset cues, the gaze cuing effect occurred when cue-target intervals were short, and it occurred in response to nonpredictive cues. However, unlike exogenous attention, the orienting was produced by a central cue and was not replaced by a reversal of the cuing effect at long cue-target intervals (inhibition of return, or IOR). These differences indicated that social cues such as gaze direction might produce a unique type of reflexive orienting. The second study confirmed that the gaze cuing effect reflects a gaze-triggered shift of spatial attention with its own unique time course. In the third study, the relationship between this gaze-triggered orienting and endogenous attention was investigated. Results indicated that orienting to gaze direction occurs independently of endogenous orienting, and that it is more strongly reflexive than orienting to central arrow cues. The fourth experiment investigated the relationship between gaze-triggered orienting and exogenous attention, and found that reflexive attention to gaze direction and reflexive inhibition to an abrupt onset (IOR) are separable processes that can co-occur. In the final set of experiments, eye movement data were collected. Reflexive orienting to gaze direction was observed in both covert and overt attentional response tasks, and it was not affected by manipulations that engage and disengage the oculomotor system. Taken as a whole, the current work provides evidence that adults shift attention in a reflexive manner in response to perceived gaze direction, and that this attention shift is different and separable from traditional forms of orienting. Additionally,

the results of these behavioral studies suggest that orienting to gaze direction is mediated primarily by cortical brain mechanisms.

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION 1
Gaze Perception and Joint Visual Attention 2
Measuring Shifts of Spatial Attention 3
Measuring the Attentional Effects of Gaze Direction 4
Gaze Direction May Produce a Unique Type of Orienting 7
Thesis Overview 9
References 11

CHAPTER 2: REFLEXIVE ORIENTING IS TRIGGERED BY NONPREDICTIVE GAZE 15
Introduction 16
Method 17
Results 20
Discussion 23
Endnotes 27
References 32

CHAPTER 3: DOES GAZE DIRECTION REALLY TRIGGER A SHIFT IN ATTENTION? 35
Introduction 36
Method 39
Results 43
Discussion 45
Endnotes 47
References 51

CHAPTER 4: REFLEXIVE AND VOLITIONAL ORIENTING TO DIRECTIONAL CUES: SEPARABLE ATTENTION EFFECTS UNIQUE TO BIOLOGICALLY RELEVANT GAZE STIMULI 53
Introduction 54
Experiment 1: Counterpredictive Gaze 59
Method 60
Results 63
Discussion 65
Experiment 2: Counterpredictive Arrows 68
Method 69
Results 71
Discussion 72
General Discussion 73
Endnotes 78
References 86

CHAPTER 5: ABRUPT ONSETS AND THE GAZE DIRECTION OF A SCHEMATIC FACE PRODUCE INDEPENDENT REFLEXIVE EFFECTS 89
Introduction 90
Method 92
Results 96
Discussion 99
Endnotes 106
References 110

CHAPTER 6: COVERT AND OVERT ORIENTING TO EYE GAZE DIRECTION AND THE EFFECTS OF FIXATION OFFSET 113

Introduction 114

Experiment 1: Manual Responses 119

Method 119

Results 124

Discussion 125

Experiment 2: Eye Movement Responses 125

Method 126

Results 127

Discussion 128

General Discussion 129

References 136

CHAPTER 7: GENERAL DISCUSSION 140

LIST OF TABLES

Table 2-1: Mean response times, standard deviations, and error rates for the three response conditions 30

Table 3-1: Mean response times, standard deviations, and error rates for the two conditions 49

Table 4-1: Mean response times, standard deviations, and error rates for Experiment 1 81

Table 4-2: Mean response times, standard deviations, and error rates for Experiment 2 84

Table 5-1: Mean response times, standard deviations, and error rates 108

Table 6-1: Mean response times and standard deviations for Experiment 1 132

Table 6-2: Mean response times and standard deviations for Experiment 2 134

LIST OF FIGURES

Figure 2-1: Examples of cued, uncued, and neutral trial sequences 29

Figure 2-2: Mean response times as a function of cue-target SOA and cue validity for the detection, localization, and identification response conditions, and for the three response conditions combined 31

Figure 3-1: Illustration of stimuli and examples of cued, uncued, and straight-gaze trial sequences for the 1-object condition and the 2-object condition 48

Figure 3-2: Mean response times as a function of cue-to-target stimulus onset asynchrony (SOA) and cue validity for the 1-object and 2-object conditions 50

Figure 4-1: Illustration of the trial sequence in Experiment 1 79

Figure 4-2: Illustration of the three trial types that were possible when gaze was directed at one of the four target locations in Experiment 1 80

Figure 4-3: Experiment 1 mean response times for counterpredictive gaze cues as a function of cue-target stimulus onset asynchrony (SOA) and trial type 82

Figure 4-4: Illustration of the trial sequence in Experiment 2 83

Figure 4-5: Experiment 2 mean response times for counterpredictive arrow cues as a function of cue-target stimulus onset asynchrony (SOA) and trial type 85

Figure 5-1: Illustration of the trial sequence for each of the five possible trial types 107

Figure 5-2: Mean response times as a function of trial type and gaze cue-to-target stimulus onset asynchrony (SOA) 109

Figure 6-1: Illustration of stimuli and examples of cued, uncued, and straight-gaze trial sequences for the simultaneous and overlap conditions in both Experiment 1 and Experiment 2 131

Figure 6-2: Mean response times as a function of gaze cue validity and fixation offset condition for Experiment 1 133

Figure 6-3: Mean response times as a function of gaze cue validity and fixation offset condition for Experiment 2 135

Chapter 1

Introduction

Gaze Perception and Joint Visual Attention

It is evident from our everyday experience that people tend to orient in response to the social attention cues of others; for example, we often turn automatically to look where someone else is looking. Given that the gaze direction of a conspecific could serve as a cue to environmental events critical to survival, it is perhaps not surprising that present day humans are highly attuned to eyes and gaze direction. Indeed, for adult humans, eyes are the most salient facial feature (e.g., Maruyama, Masame, & Endo, 1988), and psychophysical studies have shown that people are able to discern small differences in gaze angle with remarkable accuracy (Gibson & Pick, 1963; Cline, 1967). We also know that from a very early age, babies look preferentially at faces and eyes (Maurer, 1985), and that by three months they are able to discriminate changes in an adult's eye direction (Hains & Muir, 1996). Preferential looking at eyes and the ability to discern and follow gaze direction have also been observed in several nonhuman primate species (Nahm, Perret, Amaral, & Albright, 1997; Povinelli & Eddy, 1996; Emery, Lorincz, Perrett, Oram, & Baker, 1997).

The emergence of the tendency to look spontaneously to where someone else is looking has been studied extensively with human infants. Early gaze following abilities are usually assessed using the standard joint attention paradigm (Scaife & Bruner, 1975; Butterworth & Jarrett, 1991; Corkum & Moore, 1995), in which an infant is seated across from an experimenter who establishes eye contact with the infant and then makes an overt attentional shift such as a head turn to a target location. Infants under six months will follow an adult head turn in the correct direction, but only if the targets are within their visual field (e.g., D'Entremont, Hains, & Muir, 1997); and by approximately nine months, they will follow head turns in the correct direction even if the target is initially not within their visual field (e.g. Corkum & Moore, 1998). It is well established that by no later than about 18 months, infants will reliably follow a shift in gaze direction even when it is not accompanied by a corresponding head turn (e.g., Corkum & Moore, 1998; but see also a recent study by Hood, Willen, and Driver (1998) suggesting that infants as young as 10 weeks orient to gaze shifts alone). These findings suggest that orienting to where someone else is looking may be fundamental to human behavior.

Measuring Shifts of Spatial Attention

If orienting to gaze direction is fundamental, attentional cuing studies should reveal this. In the standard visual attention cuing paradigm (e.g., Posner, 1980; Posner, Cohen, & Rafal, 1982), participants press a computer key or make an eye movement in response to the appearance of a visual target, and their response time (RT) is recorded. In such studies, a cue indicating a possible target location precedes the onset of the target, and participants are usually found to be faster to respond to a target appearing at a cued location than at an uncued location. This cuing effect reflects the fact that attention has been directed to the target location by the cue. The cuing effect can be found both when participants' attentional response to the target is overt (i.e., they make an eye movement toward the location indicated by the cue), and when their attention is covert (i.e., they are instructed not to move their eyes, or the target appears too quickly after the onset of the cue to allow for an eye movement).

There is much evidence from studies of visual attention for the existence of two different types of orienting (e.g., Briand & Klein, 1987; Jonides, 1981; Müller & Rabbitt, 1989). Exogenous, or reflexive stimulus-driven orienting is usually observed when subjects respond to the sudden onset of a peripheral cue, such as the brightening of a box on a computer screen. Three characteristics of reflexive orienting to peripheral cues are: it can be produced with a very short (e.g., 100 ms) time interval between the cue stimulus and the target stimulus (i.e., a short stimulus onset asynchrony, or SOA); it occurs even when the participant knows that the cue is spatially nonpredictive; and it usually does not occur at longer (e.g., 500 ms) cue-target SOAs. Indeed, at longer SOAs, the RT advantage for cued locations is usually replaced by an RT disadvantage for cued locations, a phenomenon known as inhibition of return (IOR) (Posner & Cohen, 1984; for a recent review see Klein, 2000). In contrast, with endogenous, or volitional top-down orienting, attention shifts are most typically produced by presenting the subject with a central symbolic cue (such as an arrow) that directs attention to a peripheral location. This type of spatial orienting is slower to emerge than exogenous orienting (i.e., it requires a longer SOA), and it is typically produced by a cue that is predictive of where a target will occur.

Measuring the Attentional Effects of Gaze Direction

Friesen and Kingstone (1998), followed by Driver et al. (1999) and Langton and Bruce (1999), were the first to employ the attentional cuing paradigm to measure attentional orienting in response to gaze direction. In these studies, a centrally presented gazing face served as the cue, and RT to a subsequently presented peripheral target was examined as a function of whether the target occurred at the cued (gazed-at) location or at an uncued location. In all three studies, RT was facilitated for cued targets compared with uncued targets, indicating that gaze direction triggers a shift of spatial attention to the gazed-at location. These studies are summarized below; the Friesen and Kingstone study is reported in detail in Chapter 2 of this dissertation.

Friesen and Kingstone (1998) presented adult observers with a schematic face at central fixation that gazed nonpredictively to the left, to the right, or straight ahead, followed by a target letter to the left or right of the face. RT performance was measured in target detection, localization, and identification response conditions. Across all three conditions, RT was facilitated for cued (gazed-at) targets compared with uncued targets at 105, 300, and 600 ms SOA, and the effect had disappeared at 1005 ms SOA. Because this cuing effect emerged early, did not persist at the longest SOA, and occurred in response to cues that were not predictive of target location, Friesen and Kingstone concluded that gaze direction triggers a shift of attention that is reflexive in nature.

In the Langton and Bruce (1999) study, adult observers were presented with a scanned photograph of a face with its head turned and eyes gazing in one of four directions: left, right, up, or down. The subjects' task was to maintain fixation on a central cross, and to indicate detection of a target letter appearing to the left or right or above or below the face by pressing the spacebar on a computer keyboard. In the first of Langton and Bruce's three experiments, gaze was predictive of the axis on which the target would appear (horizontal or vertical) but not of the actual target location (left or right / up or down); cues were thus 50% predictive of target location on the given axis. RTs were compared between cued trials (in which the target appeared at a gazed-at location) and uncued trials (in which the target appeared at a location that was not gazed at) at 100, 500, and 1000 ms SOA. The results showed that subjects were significantly faster to respond to the target on cued trials at 100 ms SOA, but not at 500 or 1000 ms SOA. In their second experiment, head and gaze were completely nonpredictive of target location; therefore, on any trial, there was a 25% chance that a target would appear at the gazed-at location. Subjects in this experiment were again faster to respond to cued targets than to uncued targets at 100 ms SOA but not 1000 ms SOA (the 500 ms SOA had been dropped). In the third experiment, predictiveness was manipulated so that the target was three times more likely to appear at the cued location than at any one of the uncued locations. Responses were now faster on cued trials at both 100 ms SOA and 1000 ms SOA. Langton and Bruce concluded that their head and gaze cues engaged reflexive attention in their first two experiments (because the cuing effect occurred in response to nonpredictive cues, and because the effect emerged rapidly and did not persist at longer SOAs), and that the head and gaze cues engaged both reflexive and voluntary attention when predictiveness was added in the third experiment (because in addition to the early cuing effect, there was now an effect at the long 1000 ms SOA).

The Driver et al. (1999) study also used scanned photographs of real faces, but in this study only gaze direction was manipulated (i.e., the head was always oriented towards the viewer). In one experiment, a central face appeared with eyes closed, and then the eyes opened to reveal gaze either to the left or right. Driver et al. found that when gaze direction was not predictive of target location, subjects were faster to identify a cued (gazed-at) target letter than an uncued target letter at a relatively short cue-target SOA of 300 ms, and that this gaze cuing effect was fairly prolonged, persisting at 700 ms SOA. In a subsequent experiment, Driver et al. manipulated the predictiveness of the gaze cue such that eye direction was 80% predictive of the target's appearance on the side opposite to where the eyes were looking. They found that at the 300 ms SOA subjects were still faster to respond to targets that appeared on the side where the eyes were looking, but that at 700 ms SOA there was a trend towards faster responses to targets appearing at the predicted location. Like the Friesen and Kingstone (1998) and Langton and Bruce (1999) studies, this study provided evidence for reflexive orienting to gaze direction at a short SOA, with endogenous influences possibly beginning to emerge at a longer SOA.

Gaze Direction May Produce a Unique Type of Orienting

Behavioral differences from standard reflexive orienting

There are at least three important differences between the gaze cuing studies (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999) and previous experiments that have studied reflexive orienting. First and foremost is that in the gaze studies, the attentional cue was presented at central fixation. Typically, a reflexive attentional shift is produced by a nonpredictive abrupt onset serving as a cue at a peripheral location, and then the target appears either at that location or at a different location. Thus, in previous studies of reflexive attention, the cue has been bound to the location of a possible target, whereas in the gaze studies the cue triggers an attentional shift from fixation to a different location. In this way, gaze cues are similar to the symbolic central cues (such as arrows) that have been used to induce voluntary attentional shifts to peripheral locations by predicting that a target will appear in the periphery (see Klein, Kingstone, & Pontefract, 1992 for a review). The fact that a nonpredictive centrally presented gaze cue can initiate a reflexive shift of attention to a peripheral location suggests that attention to gaze direction may represent a special form of attention.

A second difference is that the time course of reflexive orienting to gaze direction is different from both reflexive orienting to peripheral onsets and voluntary orienting in response to predictive central cues. In traditional studies of reflexive orienting to peripheral onsets, facilitation for targets appearing at cued locations emerges early (at less than 100 ms SOA), and disappears shortly thereafter. In the gaze studies, facilitation occurred at an early SOA of 100 ms (Friesen & Kingstone, 1998; Langton & Bruce, 1999), as in the studies of reflexive attention to peripheral onsets; but it persisted much longer (at 600-700 ms SOA) (Driver et al., 1999; Friesen & Kingstone, 1998).

A third difference between the results of the gaze cuing studies and the usual findings in experiments producing reflexive orienting is the absence of inhibition of return (IOR) at a long cue-target interval. In studies of reflexive orienting to peripheral cues, the cuing effect seen at short SOAs becomes reversed at longer SOAs. It is thought that when there is a longer interval between the appearance of the cue and the target, a subject is slower to respond to the cued location because attention has been committed to and subsequently removed from the cued location, and is then inhibited in returning to a previously inspected location (Posner & Cohen, 1984). In the gaze cuing studies, the cuing effect was never reversed at a longer SOA.

These three differences -- a difference in the spatial relationship between cue location and target location, the different time courses, and the absence of IOR in the gaze studies -- raise the possibility that reflexive orienting in response to nonpredictive gaze direction and reflexive orienting to nonpredictive peripheral cues may be qualitatively different forms of reflexive orienting.

Possible brain pathways underlying reflexive attention to gaze direction

Not only does orienting to gaze direction exhibit a unique behavioural profile; it also likely occurs by way of different neural pathways from those subserving reflexive orienting to abrupt peripheral onsets. There is a wealth of evidence that the exogenous attentional phenomena of orienting rapidly to an abrupt onset and of IOR, are subserved by subcortical brain regions, particularly the superior colliculus (Rafal, Calabresi, Brennan, & Sciolto, 1989;

Rafal, Posner, Friedman, Inhoff & Bernstein, 1988; Rafal, Henik, & Smith, 1991), working in concert with parietal cortex. In contrast, convergent evidence from several different research areas suggests that cortical pathways play a major role in reflexive orienting to gaze direction. Single cell recording studies with monkeys have revealed that there are cells in inferior temporal cortex (IT) responsive to faces and eyes (for a review, see Desimone, 1991), which project to cells in the superior temporal sulcus (STS) responsive to particular gaze directions (Campbell, Heywood, Cowey, Regard, & Landis, 1990; Perrett et al., 1985), which in turn share reciprocal connections with cells in the parietal cortex (Harries & Perrett, 1991). Given that eyes would have to be perceived as eyes before they could cause a reflexive attentional shift, and given that the parietal lobe is known play a major role in spatial attention, this cortical IT to STS to parietal pathway seems a likely network through which brain mechanisms specialized for gaze processing might trigger reflexive shifts of attention.

There is also evidence from human studies that cortical areas play a major role in attention to gaze direction. In a recent behavioural study of split-brain patients, reflexive attention to gaze direction occurred only in the hemisphere specialized for face processing (Kingstone, Friesen, & Gazzaniga, 2000). Also recently, functional neuroimaging studies have found selective activation in temporal areas analogous to the monkey STS, as well as in parietal cortex, in response to gaze direction (Hoffman & Haxby 1999; Hooker et al., 2001; Wicker, Michel, Henaff, & Decety, 1998).

Thesis Overview

The general goal of the present work is to investigate the nature of attentional orienting in response to gaze direction. Because gaze-triggered orienting has only recently been studied using attentional methodologies, there are many unanswered questions, some of which are addressed in this thesis. For example: Is it a unique form of orienting? How strongly reflexive is it? How does it compare with traditionally studied exogenous and endogenous orienting? Is it independent of each of these? Does it interact with the generation of eye movements? And what are the brain pathways by which it might occur?

As was discussed earlier in this chapter, attention shifts can be overt (i.e., eye movements are made) or covert (no eye movements are made), and they can also be exogenous (reflexive) or endogenous (volitional). A general strategy of the present work is to explore the attentional effects of gaze direction with reference to these distinctions. Chapter 2 presents the initial investigation of the effects of nonpredictive gaze direction (covert exogenous). The study reported in Chapter 3 tests an alternative explanation for the results obtained in Chapter 2, and confirms that gaze direction cues do indeed trigger a reflexive shift of attention (covert exogenous). In Chapter 4, counterpredictive gaze and arrow cues are compared in order to investigate whether reflexive gaze-triggered orienting and volitional orienting are independent attentional phenomena, and also whether biologically-relevant gaze cues produce orienting that is more strongly reflexive than that produced by biologically-irrelevant arrow cues (covert exogenous, covert endogenous). Chapter 5 examines the question of whether reflexive attention to gaze is independent of the reflexive IOR phenomenon (covert exogenous). And finally, in Chapter 6, the relationship between reflexive attention to gaze direction and the oculomotor system is examined by comparing manual responses with eye movement responses (covert exogenous, overt exogenous).

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Chapter 2

Reflexive orienting is triggered by nonpredictive gaze

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Introduction

A moment's introspection reveals that in everyday life, gaze shifts can provide a rich and complex source of social information. For instance, at a loud party one can communicate the desire to leave by simply "catching" a friend's eye and then looking toward the door. The use of gaze shift as a social cue would, of course, have had many evolutionary advantages as well. For example, a sudden shift in gaze could signal the occurrence of crucial events in the environment, such as the approach of a predator or the presence of a food source.

Given the wealth of information that gaze shifts can provide, it is not surprising to discover that lesion and single-cell recording studies with nonhuman primates indicate that specific brain areas are specialized for the processing of gaze information. For instance, in single-cell recording experiments with the macaque monkey, Perrett and his colleagues have found specific cells in the superior temporal sulcus (STS) that respond to particular orientations of both head and gaze (Perrett et al., 1985). And similarly, Campbell, Heywood, Cowey, Regard, and Landis (1990) have found that STS lesions in the rhesus monkey impair gaze direction discrimination.

Research with human infants suggests that the development of these specialized brain areas begins to affect behavior at a very young age. As early as two to three months, babies look preferentially at the eyes of a schematic face (Maurer, 1985), and by three months they are also able to discriminate changes in an adult's eye direction (Hains & Muir, 1996). In the second half of their first year, infants begin to show the ability to look in the same general direction as an adult's gaze and head turn. And by the age of 12 months, infants reliably look to where someone else is looking, regardless of whether a shift in gaze is accompanied by a head turn (Corkum & Moore, 1995; but see a recent study by Hood, Willen, and Driver (1998) suggesting that infants as young as 10 weeks orient to gaze shifts alone).

The goal of the current study was to explore whether gaze shifts would produce shifts of attention in adults. Our manipulation was very simple, yet, as we will show, very powerful. We modified the standard Posner cuing paradigm (Posner, 1978; Posner, 1980) so that subjects were presented with a schematic face[1] that looked left, right, or straight ahead. They were instructed to maintain fixation on the face at all times, and they were informed that the gaze direction of the schematic face did not, in any way, predict the location of the response stimulus.

Our findings indicate that response time (RT) was facilitated when a target appeared at the location where the eyes were looking (the cued location). This facilitation effect occurred early, was relatively short-lived, and was not accompanied by any RT delay at the uncued location. These findings bear the hallmarks of reflexive shifts of covert attention (Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Jonides, 1981).

Method

Subjects

Twenty-four introductory psychology students (19 females and 5 males) participated in the present experiment for course credit. All participants reported normal or corrected-to-normal vision. Testing time totaled approximately two hours, and was divided between two days.

Apparatus

The experiment was controlled by a 6100 Power Macintosh computer, with stimuli presented on a 14-inch Apple color-monitor set to black and white. RT and accuracy measures were based on keyboard responses.

Participants were seated approximately 57 cm from the monitor, and the experimenter ensured that subjects were centered with respect to the monitor and keyboard.

Stimuli

The target stimulus demanding a response was a black capital letter F or T measuring 0.8° wide and 1.3° high. The face display, shown in Figure 2-1, consisted of a white background with a black line drawing of a round face subtending 6.8° and centered in the middle of the monitor. The face contained two circles representing the eyes, a smaller circle representing the nose and fixation point, and a straight line representing the mouth. The eyes subtended 1.0°, and were located 1.0° from the central vertical axis and 0.8° above the central horizontal axis. The nose subtended 0.2°. The mouth was 2.2° in length and was centered 1.3° below the nose. Black filled-in circles appeared within the eyes and represented the pupils. The pupils subtended 0.5°, were centered vertically in eyes, and were either just touching left, just touching right, or centered in eyes. The target letters were presented 5.0° to the left or right of the eyes, as measured from the center of the nearest eye to the center of the target letter.

---------- Insert Figure 2-1 about here ----------

Design

The experiment consisted of detection, localization, and identification response conditions, and all subjects participated in all three conditions. Two of the response conditions were presented on the first day of testing, and one condition was presented on the second day. The order of response conditions was counterbalanced across subjects. Each of the three conditions was composed of 500 trials, with a block of 20 practice trials preceding 10 test blocks of 48 trials each. Additionally, for half of the subjects, the detection condition included 30 catch trials (no target presented) randomly selected from the three gaze direction cues. (In this case there were 10 test blocks of 51 trials.) On target trials, gaze direction, target location, target identity, and cue-target stimulus onset asynchrony (SOA) duration were selected randomly and equally within each block.

Procedure

Figure 2-1 provides a representative illustration of the sequence of events on a target trial. The start of a trial was signaled by the presentation of a face with blank eyes. After 680 ms, pupils appeared within the eyes, looking either left, right, or straight ahead. Following this cue, a target letter appeared to the left or right of the face. The face, pupils, and target remained on the screen until a response was made or 2700 ms had elapsed, whichever came first. The intertrial interval was 680 ms.

Cue-target SOA, measured from the appearance of the pupils to the appearance of the target, was selected from four possible durations: 105, 300, 600, and 1005 ms. On cued-target trials, the eyes looked left or right, and a target appeared at the location where the eyes were looking; and on uncued-target trials, the eyes looked left or right, and a target appeared at the location where the eyes were not looking. On neutral trials, the eyes looked straight ahead, and a target could appear to the left or right of the face.

In the detection response condition, participants were instructed to indicate that they had detected the appearance of a target on the screen by pressing the space bar on the computer keyboard with the index finger of their preferred hand. If a target did not appear, subjects were not to respond. In the localization condition, participants were instructed to indicate whether a target appeared to the left or right of the face by pressing the "z" key with their left index finger for a target on the left, and the "/" key with their right index finger for a target on the right. In the identification condition, participants were instructed to indicate the identity of the target letter by pressing the "z" key with their left index finger for the target letter F and the "/" key with their right index finger for the target letter T. For the localization and identification conditions, the "z" and "/" keys were labeled with coloured stickers indicating L and R (localization), or F and T (identification).

Before beginning each response condition, subjects were told that a drawing of a face with blank eyes would appear in the center of the screen signaling the start of each trial, and that it was important that they fixate their eyes on the nose in the center of the face while it was on the screen. Subjects were told that after the appearance of the face, pupils would appear in the eyes looking either left, right, or straight ahead, and that after that, a letter (either F or T) could appear either to the left or right of the face. Participants were informed that the direction in which the eyes looked was not predictive of the location or identity of the target letter, or of when it would appear, and they were instructed to respond as quickly and accurately as possible to the target.

Participants were informed of the number of trials and blocks in each response condition, and they were instructed to press the space bar to initiate each new block of trials after they had taken a rest break and were ready to proceed. Before they began the experiment, they were offered an opportunity to ask questions about the procedure, and were reminded once more of the importance of maintaining central fixation.

Results

Anticipations, incorrect responses, and timed-out trials were classified as errors and were excluded from analysis. Error data are shown in Table 2-1. Anticipations, defined as responses with a latency of less than 100 ms, accounted for 0.44% of the target trials in the detection condition, 0.05% of the trials in the localization condition, and 0.01% of the trials in the identification condition. Keypress selection errors accounted for 0.01% of the target trials in the detection condition, 1.35% of the trials in the localization condition and 4.82% of the trials in the identification condition. Timed-out trials accounted for less than 0.02% of the test trials in each of the three response conditions. In the detection condition, the false alarm rate for the twelve subjects given catch trials was 2.8%. The overall error rate in the detection condition was identical (0.47%) whether or not subjects received catch trials.

---------- Insert Table 2-1 about here ----------

A 3-way analysis of variance (ANOVA) was conducted on the percent errors, with SOA (105, 300, 600, and 1005 ms), cue validity (cued-target, neutral, and uncued-target), and response condition as within-subject factors. There was a main effect of response condition [$F(2,23) = 37.630$, $p < 0.0001$], reflecting that the error rate increased across detection, localization, and identification conditions, respectively. Error rate did not vary significantly as a function of SOA or cue validity, and there were no significant interactions [all F's < 2.5, all p's > 0.10].

The Three Response Conditions

Mean RTs for the detection, localization, and identification response conditions are presented in Table 2-1 and illustrated in Figure 2-2 (see 2-2(a), 2-2(b), and 2-2(c)). For each response condition, a separate ANOVA was conducted with SOA (105, 300, 600, and 1005 ms) and cue validity (cued-target, neutral and uncued-target) as within-subject factors. As indicated below, analysis confirmed that for each response condition, RT was facilitated on cued-target trials relative to neutral and uncued-target trials. Additionally, response latencies became shorter as the cue-target SOA lengthened, reflecting a standard foreperiod effect (Bertelson, 1967; Mowrer, 1940). The SOA x cue interaction was never significant.

---------- Insert Figure 2-2 about here ----------

For the *detection* condition, the ANOVA results were: SOA [$F(3,23) = 31.782$, $p < 0.0001$], cue [$F(2,23) = 9.920$, $p < 0.0003$], and SOA x cue [$F(6,23) = 1.286$, $p > 0.25$]. In the *localization* condition: SOA [$F(3,23) = 41.441$, $p < 0.0001$], cue [$F(2,23) = 21.710$, $p < 0.0001$], and SOA x cue [$F(6,23) = 1.112$, $p > 0.35$]. In the *identification* condition: SOA [$F(3,23) = 14.543$, $p < 0.0001$], cue [$F(2,23) = 7.386$, $p < 0.005$], and SOA x cue [$F(6,23) = 1.442$, $p > 0.20$].

These analyses suggest that performance as a function of SOA and cue did not vary significantly across the different response conditions. This was confirmed by an ANOVA that included response condition as a within-subject factor. There was now a main effect of response condition [$F(2,23) = 194.140$, $p < 0.0001$], with RT being fastest for detection responses and slowest for identification responses, with localization responses falling in the middle. As before, the main effects for SOA [$F(3,23) = 49.482$, $p < 0.0001$] and cue [$F(2,23) = 39.500$, $p < 0.0001$] were highly significant. The only significant interaction was between response condition and SOA [$F(6,23) = 2.703$, $p < 0.0164$], reflecting the fact that the while the foreperiod effect was the same for all response conditions up to the 600 ms SOA, it varied at the longest SOA. At 1005 ms, while RT continued to fall in the detection condition, it held steady in the localization condition, and became slower in the identification condition. When the 1005 ms SOA was removed from the analysis, the response condition x SOA interaction disappeared [$F(4, 23) < 1.0$, $p > 0.45$.]. No other interactions approached significance [all F's < 2, all p's > 0.15]. Figure 2.2(d) presents the mean RTs collapsed across response conditions as a function of SOA and cue.

Figure 2-2 suggests that the cuing effect may have disappeared at the longest SOA. To test this observation, we conducted individual *t*-tests on the valid versus invalid RTs at each SOA, collapsed across response condition. Results indicate that there was a cuing effect at the 105, 300, and 600 ms SOAs [all t's $(23) > 2.85$, all p's < 0.005], but no cuing effect at the longest 1005 ms SOA [t $(23) < 1.20$, $p > 0.23$]. [2]

Figure 2-2 also suggests that the significant cuing effects were due to facilitation at the cued location relative to the neutral and uncued locations, with no significant difference between the latter two. That is, it appears that gaze direction is producing an attentional benefit (RT at the cued location < RT at the neutral location) with no attentional cost (RT at the neutral location = RT at the uncued location). To test this observation, we conducted two tests at each of the significant SOAs, one to assess the attentional benefits of the gaze cue (cued vs. neutral RTs), and one to assess the attentional costs (uncued vs. neutral RTs). These tests revealed that there was a significant RT benefit at the 105, 300 and 600 ms SOAs [all t's $(23) > 2.66$, all p's < 0.01], and no attentional cost [all t's $(23) < 1.33$, all p's > 0.18].

Discussion

The adult subjects in our study fixated on a simple line drawing of a face looking left, right, or straight ahead. Despite the fact that they were told that gaze direction did not predict where the target would occur, subjects were fastest to respond to the target when gaze was directed towards the target. This effect was reliable for three very different types of target response: detection, localization, and identification.

It is our position that the facilitation effect produced by the gaze cue reflects the involvement of exogenous (reflexive) covert[3] attention. There are at least four pieces of evidence that converge on the conclusion that the orienting is reflexive: (1) the cuing effect emerged rapidly (appearing at the short 105 ms cue-target SOA in two of the three response conditions and by the 300 ms SOA in all conditions), (2) it occurred even though the participant was informed that the gaze cue did not predict the target location, (3) it exhibited a relatively short time course (disappearing by the 1005 ms cue-target SOA), and (4) it was characterized by benefits at the cued location (cued-target RT < neutral RT) without costs at the uncued location (uncued-target RT = neutral RT). Each of these findings possesses the signature of exogenous orienting. For instance, it is widely reported that compared to endogenous (volitional) orienting, exogenous orienting emerges quickly (Cheal & Lyon, 1991); it occurs whether the cue is predictive or not (Jonides, 1981); it persists for a relatively short duration (Müller & Rabbitt, 1989); and it produces benefits without costs (Posner & Snyder, 1975)[4].

An important difference between our study and previous experiments that have studied reflexive orienting to a peripheral location is that in our study, the attentional cue was presented at central fixation. Typically, a reflexive attentional shift is produced by a nonpredictive abrupt onset occurring at a peripheral location. In contrast, central cues have been used to induce voluntary attentional shifts to peripheral locations by predicting that a target will appear in the periphery (see Klein, Kingstone, & Pontefract, 1992 for a review). The fact that a nonpredictive centrally presented gaze cue can initiate a reflexive shift of attention to a peripheral location suggests that the human brain may be specialized to shift attention in response to gaze direction.

A wealth of convergent evidence implicates the parietal cortex in spatial orienting (for a review, see Posner & Petersen, 1990). Research with nonhuman primates indicates that gaze direction is analyzed in the STS of the temporal cortex (e.g., Perrett et al., 1985; Campbell et al., 1990) and in the amygdala (Kling & Brothers, 1992). Rich reciprocal connections between the amygdala and the STS (Young et al., 1995), and between the STS and parietal cortex (Harries & Perrett, 1991), provide a likely network through which brain mechanisms specialized for gaze processing might trigger reflexive shifts of attention.

It should be noted that in our study, reflexive orienting to gaze direction occurred without giving rise to the inhibition of return (IOR) phenomenon. In studies of reflexive orienting to nonpredictive peripheral cues, IOR is typically revealed as delayed RT at a cued/attended location relative to an uncued/unattended location when the cue target-SOA exceeds 300 - 500 ms. The absence of IOR in the present study raises the possibility that there might be interesting differences between reflexive orienting in response to nonpredictive gaze direction and reflexive orienting in response to nonpredictive peripheral cues. Because IOR is known to be dependent upon the activation of the superior colliculus (Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Posner, Friedman, Inhoff & Bernstein, 1988), it is our speculation that in the present study, a reflexive shift of attention in response to gaze direction may not have involved activation of the superior colliculus.

Some investigators hold that shifting attention in response to gaze direction is an important step in the development of a theory of mind (Butterworth & Jarrett, 1991; Baron-Cohen, 1995). An alternative view is that attentional shifts to gaze direction might merely reflect the development of an appreciation that gaze direction can be an important cue to interesting aspects within the environment (Corkum & Moore, 1995). Our study does not favour either position, although it does highlight the powerful effect that gaze direction can have on attentional orienting. Our adult subjects shifted attention in response to an elementary, schematic face that looked left or right. They knew that the face was not a real face and that it did not represent a person with a mind, and they also knew that the face's gaze was not predictive of an important environmental event. Nevertheless, their attention was shifted reflexively over hundreds of trials.

Our study demonstrates that a nonpredictive shift in gaze can trigger reflexive orienting. This orienting occurs across a wide variety of responses; it appears rapidly and is short lived; it is revealed as RT benefits at the cued (gazed at) target location without any corresponding RT cost at an uncued target location; and it appears to be so fundamental that it can be triggered solely by the gaze of a simple schematic face.[5]

Endnotes

[1] There is evidence to suggest that people respond as well to schematic eyes and faces as they do to real faces (Von Grünau & Anston, 1995). We reasoned that if the attentional effect of gaze direction were robust, a basic face-like stimulus would produce the effect while minimizing extraneous complexities associated with real faces (e.g., face asymmetry, hair, gender, etc.).

[2] An analysis of cued versus uncued RTs within the individual response conditions confirmed that there was a cuing effect for the three shortest SOAs in all three conditions, with the exception of the 105 ms SOA in the identification condition.

[3] Although we did not monitor subjects' eye movements in our study, we are confident that eye movements to the cued location were not involved in producing our cuing effect. It is well known that for simple detection tasks (such as our detection and localization response conditions) subjects will spontaneously avoid making eye movements to the target (Posner, 1980). Additionally, if eye movements were responsible for our cuing effects, one would expect to observe both RT benefits and RT costs. We only found RT benefits. Finally, one would also expect the cuing effect to persist at the 1005 ms SOA. It did not.

[4] Posner and Snyder (1975) established that stimulus-driven exogenous activation produces benefits without costs. Interestingly, exogenous spatial orienting has rarely satisfied this criterion, producing RT costs as well as benefits. This may be due to the fact that there is no obvious neutral condition for a peripheral exogenous spatial cue. The present study would seem to be an exception, with the eyes-straight-ahead serving as a natural neutral condition.

[5] A recent target detection study by Langton and Bruce (1999; see also Driver et al., 1999) found evidence of reflexive orienting to centrally presented photographs of human faces that were turned to the left, to the right, up, and down. Although gaze direction was confounded with head orientation in Langton and Bruce's study, their finding of reflexive orienting to a centrally presented social attention cue converges with ours.

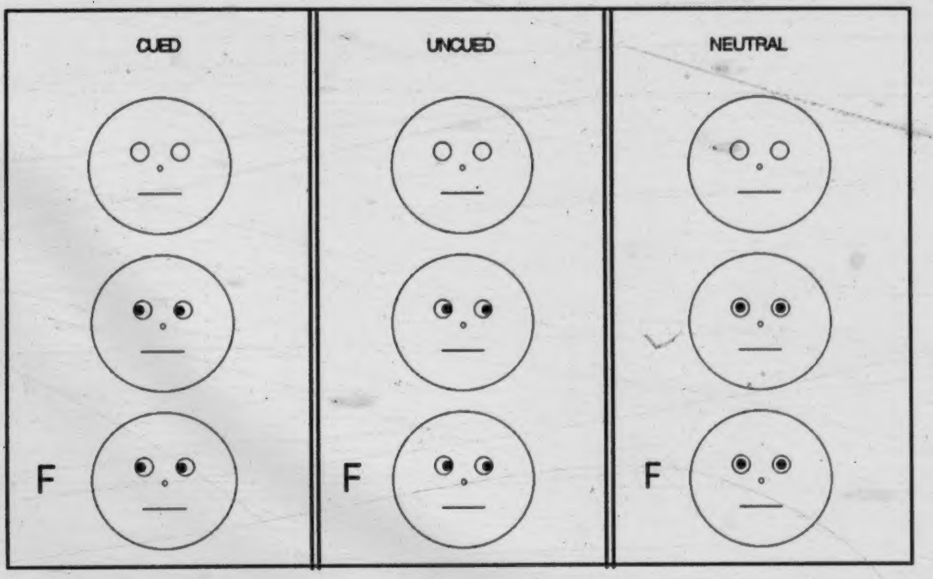

Figure 2-1. Examples of cued, uncued, and neutral trial sequences. Each trial began with the presentation of a face with blank eyes. After 680 ms, pupils appeared in the eyes, looking left, right, or straight ahead (the gaze cue). Then, after 105, 300, 600, or 1005 ms, the letter F or T (the target) appeared to the left or right of the face.

Table 2-1. Mean RTs (ms), Standard Deviations, and Error Rates (%) for the Three Response Conditions

Condition		Detection			Localization			Identification		
		M	SD	Errors	M	SD	Errors	M	SD	Errors
105 ms SOA	cued	335	59	0.10	361	56	1.25	505	56	4.69
	neutral	350	63	0.00	367	52	1.25	509	53	4.38
	uncued	347	53	0.21	373	49	1.46	507	49	4.27
300 ms SOA	cued	311	53	0.73	334	51	1.04	478	53	4.90
	neutral	321	53	0.73	350	53	2.19	488	59	5.31
	uncued	323	47	1.46	355	48	1.98	489	52	5.00
600 ms SOA	cued	309	55	0.21	327	51	1.04	469	59	3.96
	neutral	314	51	0.31	339	51	1.15	485	52	5.42
	uncued	322	51	0.83	342	43	1.46	485	59	4.58
1005 ms SOA	cued	308	51	0.42	331	50	1.04	482	62	4.58
	neutral	311	54	0.10	339	56	1.56	499	74	5.42
	uncued	311	53	0.52	337	54	1.46	483	61	5.52

Note. Errors = the percentage of test trials excluded as anticipations, key press selection errors, or timed-out trials.

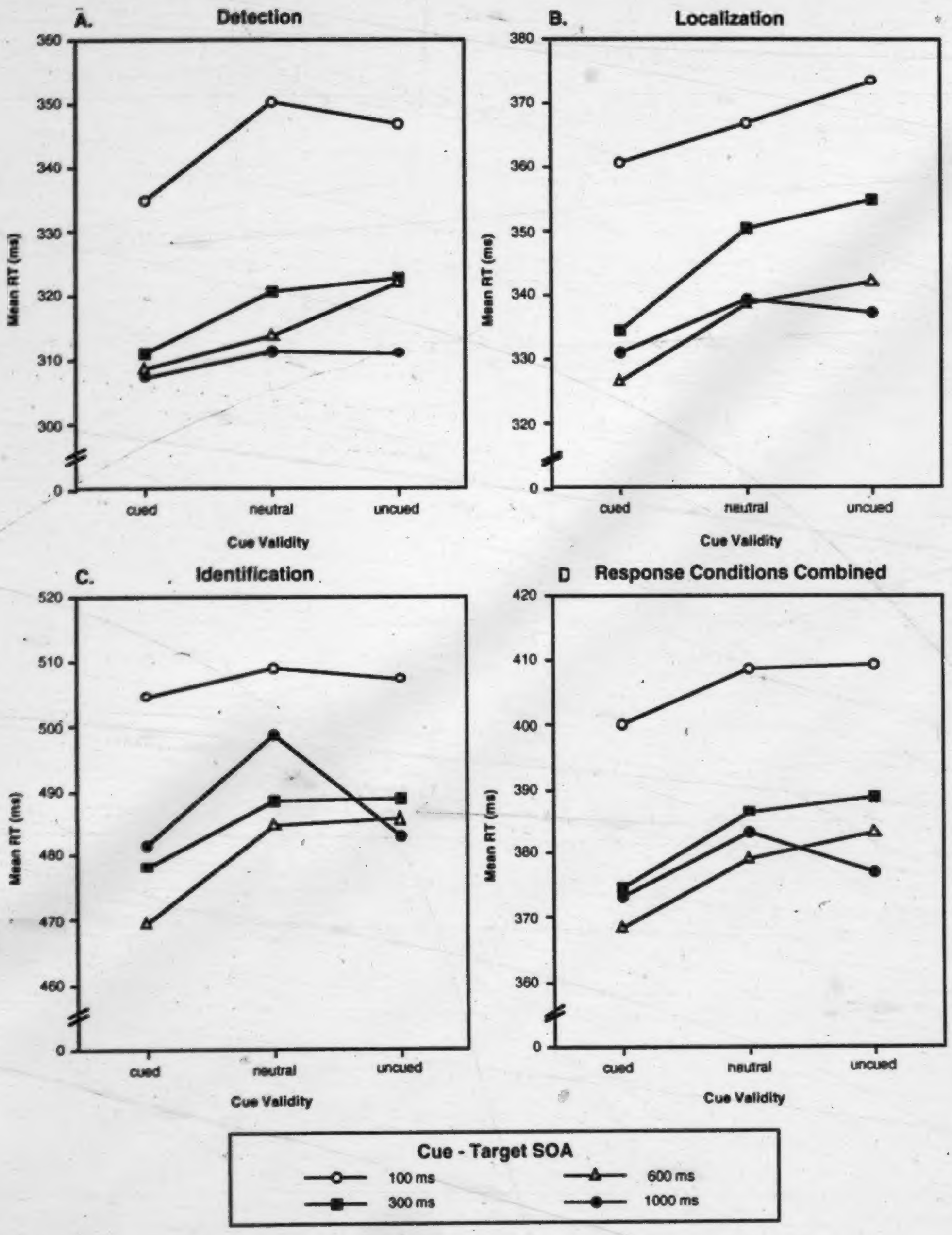

Figure 2-2. Mean RTs as a function of cue-target SOA and cue validity for the detection (a), localization (b), and identification (c) response conditions, and for the three response conditions combined (d).

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Chapter 3

Does gaze direction really trigger a shift in attention?

Introduction

Recent studies examining the attentional effects of gaze direction have presented a gazing face at central fixation as a nonpredictive directional cue, and then a single abrupt onset in the periphery as the target. The result is faster manual response time (RT) for a target appearing at the gazed-at location compared to a location that is not gazed at (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). Taken together, the gaze cuing studies found that RT facilitation for gazed-at target locations emerged as early as 100 milliseconds (ms) after target onset (Friesen & Kingstone, 1998; Langton & Bruce, 1999), persisted for 600-700 ms (Driver et. al, 1999; Friesen & Kingstone, 1998), and had disappeared by 1000 ms (Friesen & Kingstone, 1998; Langton & Bruce, 1999). The early emergence of the facilitation, coupled with the fact that it occurred with nonpredictive cues, suggested that the facilitation represented an attentional shift that was reflexive in nature.

However, the RT pattern observed in the gaze studies differed in at least two important ways from the pattern typically observed in studies that produce reflexive orienting by cuing a potential target location in the periphery with an abrupt onset at that location (e.g., Klein, Kingstone, & Pontefract, 1992; Posner, Cohen, & Rafal, 1982). One difference is that the facilitation produced by gaze persisted considerably longer than facilitation produced by abrupt peripheral onsets. And a second difference is that gaze direction cues did not produce inhibition of return (IOR), a reversal of the advantage for cued locations at longer cue-to-target stimulus onset asynchronies (SOAs) that is usually observed with abrupt peripheral onsets. These discrepancies led to the conclusion that the RT facilitation for gazed-at target locations must represent a unique type of reflexive orienting (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999).

Although the widely accepted interpretation of the results of the gaze cuing studies is that gaze direction triggers a shift of attention to the gazed-at location, there is a viable alternative interpretation. It is possible that gaze direction does not trigger a shift of spatial attention, and that the only shift of attention that occurred in these studies was exogenous orienting to the abrupt onset of the single peripheral target. That is, the RT benefit observed for gazed-at target locations might have arisen because attentional capture by the peripheral target was modulated by gaze direction at central fixation, with attentional orienting to the target onset facilitated when the eyes were directed towards rather than away from the target. If this is the case, then gaze direction does not actually produce a shift of attention; it merely modifies the speed of orienting induced by the abrupt onset of a peripheral target!

This alternative interpretation -- that the facilitation observed for targets appearing at the gazed-at location might reflect the modulation by gaze of exogenous capture by the target -- is a reasonable one, considering the evidence in the attentional literature that the ability of a peripheral stimulus to capture attention can be affected by a stimulus at central fixation. For example, Lavie (1995; Maylor & Lavie, 1998) has demonstrated that the incompatibility effect of an irrelevant peripheral distractor decreases when perceptual load at central fixation is increased. Closer to the point perhaps, Mackeben & Nakayama (1993) found that simply removing an uninformative central fixation stimulus from a display screen can speed up the deployment of reflexive attention to the location of an abrupt onset in the periphery. In a similar manner, simply having an uninformative gaze stimulus at central fixation that is congruent with a peripheral target location may speed up the deployment of reflexive attention to the target. Note that in this scenario, gaze does not trigger any shift in attention; rather, a shift in attention is triggered by the peripheral onset.

It is also worth noting that such an account can explain some of the unusual aspects of the data collected in the gaze cuing experiments. First, it can explain the unusual time course, i.e., early facilitation that persisted for a much longer time than is usually seen with reflexive orienting to abrupt onsets. This is because the prolonged facilitation would not have reflected the time course of orienting to the peripheral location in response to the gaze cue, but rather the length of time that the processing of eyes at fixation can influence the rapid attentional capture by a peripheral target. Second, and perhaps more importantly, this alternative account can elegantly explain why IOR was never observed at gazed-at target locations at longer SOAs. Simply put, if gaze direction did not trigger a shift of attention to the gazed-at location, then one would not expect to find the subsequent inhibition usually associated with an attentional shift when the target location is probed.

The goal of the present study was to test this alternative account of the gaze cuing findings. We presented nonpredictive gaze cues followed by either a target alone (1-object condition) or a target with a distractor on the opposite side of the screen (2-object condition). At the beginning of each trial, a schematic face with blank eyes was presented at central fixation. Pupils then appeared in the eyes, gazing left, right, or straight ahead. After a variable duration, a target appeared to the left or right of the face, and participants responded to the appearance of the target with a speeded keypress. In the 1-object condition, the target was the only abrupt onset in the display. In the 2-object condition, a distractor appeared at the same time as the target. If gaze direction merely modulates attentional capture by the abrupt onset of a single peripheral target, then there should be an effect of gaze direction in the 1-object condition, because a single abrupt onset occurs on one side of the target display; and there should be no effect of gaze direction in the 2-object condition, because the abrupt onset of the target on one side of the target display is always balanced by an equivalent abrupt onset on the other side of the display, thus eliminating the possibility of exogenous capture on one side or the other. On the other hand, if gaze direction actually triggers an attentional shift, there should be RT benefits for gazed-at target locations in both the 1-object condition and the 2-object condition; i.e., facilitation for a gazed-at target should occur regardless of whether a distractor is presented simultaneously to eliminate the possibility of attentional capture by the target.

Method

Participants

Forty-eight psychology undergraduates participated in the experiment for course credit. All participants reported normal or corrected-to-normal vision, and all were unaware of the purpose of the experiment.

Apparatus.

The experiment was controlled by a Macintosh computer, with stimuli presented on a 14 inch color monitor set to black and white. Participants were seated at a distance of approximately 57 cm from the monitor. Target detection response time (RT) was measured as the time interval between the onset of the target and onset of a spacebar keyboard response.

Stimuli

Stimuli and trial sequences for both the 1- and 2-object conditions are illustrated in Figure 3-1. All stimuli were black line drawings on a white background. For both conditions, the fixation display consisted of a round face subtending 6.8°. The center of the face was positioned on the vertical midline and 0.2° above the horizontal midline. The face contained two circles representing the eyes, a smaller circle representing the nose, and a straight line representing the mouth. The nose, which served as the fixation point, subtended 0.2° and was centered on the horizontal and vertical midlines. The mouth was 2.2° in length and was centered 1.3° below the nose. The eyes subtended 1.0°, and were located 1.0° from the central vertical axis and 0.8° above the central horizontal axis. Black filled-in circles appeared within the eyes and represented the pupils. The pupils subtended 0.5°, were centered vertically in eyes, and were either just touching left, just touching right, or centered in eyes. Targets and distractors were a circle subtending 1.5° and square subtending 1.5°; these were always presented such that the center of the circle or square was 0.8° above the horizontal meridian and 0.8° to the left or right of the vertical meridian.

Design

Participants were randomly assigned to either the 1-object condition or the 2-object condition. There were 24 participants in each of the two conditions. For half of the subjects in each condition the target was always a circle, and for the other half the target was always a square. In the 2-object condition, if the target was a square the distractor was a circle, and vice versa. Within each of the 1- and 2-object conditions, target identity (circle or square) was also randomly assigned.

For both the 1-object and 2-object conditions, the experiment was composed of 540 trials presented in 10 blocks of 54 trials each. 480 of the trials were target trials in which a target appeared following the gaze cue, and 60 were catch trials in which the target did not appear. On target trials, gaze direction (left, right, or straight), target location (left or right), and cue-target stimulus onset asynchrony (SOA) duration (105, 300, 600, or 1005 ms) were selected randomly and equally within each block. Similarly, on catch trials, gaze direction (left, right, or straight) was selected randomly and equally. On cued trials, gaze was directed left or right and the target appeared at the location towards which gaze was directed; on uncued trials gaze was directed left or right and the target appeared on the side opposite to where gaze was directed; and on straight-gaze trials, gaze was straight ahead and the target appeared with equal probability on either side of the face. Cued, uncued, and straight-gaze trials were equally likely.

Trial sequences are illustrated in Figure 3-1. In the 1-object condition, the start of each trial was signaled by the presentation of a face with blank eyes for 675 ms. Then pupils appeared in the eyes looking left, right, or straight ahead. On target trials, a single target appeared either on the left or right side of the screen 105, 300, 600, or 1005 ms after the gaze cue onset, and the gaze cue and the target remained on the screen until a response was made or 1500 ms had elapsed, whichever came first. On catch trials, no object appeared on the screen following the gaze cue, and the gaze cue remained on the screen for 1605 ms unless a response was made in error. The intertrial interval was 675 ms. RT was measured from the onset of the target.

The trial sequence in the 2-object condition was identical to that in the one object condition, with the important exception that following the gaze cue, two objects appeared on the screen, one to the left of the face and one to the right. On target trials, the target object appeared on one side of the face and a distractor appeared on the opposite side. The gaze cue, the target, and the distractor remained on the screen until a response was made or 1500 ms had elapsed, whichever came first. On catch trials, the distractor object appeared on both sides of the face. The gaze cue and the two distractors remained on the screen for 1605 ms, unless a response was made in error.

The participants' task was to maintain fixation on the face's nose and to make a keypress as quickly and accurately as possible when a target was detected.

Procedure

Before beginning the experiment, participants were given written instructions containing a description of the trial sequence and the experimental procedure. After they had read the instructions, a researcher repeated the instructions verbally. Both written and verbal instructions were specific to the condition (1- or 2-object) in which the participant was being run, as well as to the identity of the target (and the distractor, in the 2-object condition). Thus, for example, participants in the 2-object condition whose target was a square were told that on some trials a square and a circle would appear on the screen and on other trials two circles would appear on the screen, and that they should respond with a keypress only when a square appeared on the screen and not when both objects were circles.

Participants in the 1-object condition were told that each trial would begin with a face with blank eyes, and that shortly after the face appeared on the screen, pupils would appear in the eyes looking left, right, or straight ahead. They were told that on most trials, after the pupils appeared their target would appear either on the left or right side of the face, and they were instructed to respond by pressing the spacebar on the computer keyboard with the index finger of their preferred hand. Participants were further told that on a minority of trials the target would not appear, and that on those trials they should refrain from pressing the spacebar and simply wait for the next trial to begin. Participants were informed that the direction in which the eyes looked was not predictive of whether the target would appear or of where the target would appear. They were instructed to remain fixated on the nose of the face throughout each block of trials, and to respond as quickly and accurately as possible to the target.

Instructions to participants in the 2-object condition were identical, except that these participants were told that after the pupils appeared in the eyes, two objects would always appear on the screen, one on either side of the face. They were told that on most trials, one of the objects would be their target and the other would be the distractor, and they were instructed to respond with a speeded keypress if one of the two objects was the target. Participants were also told that on a minority of trials both objects would be the distractor (and that the target would not be present), and that on these trials they should refrain from responding.

Participants in both conditions were informed of the number of trials and blocks they would be completing, and they were instructed to press the space bar to initiate each new block of trials after they had taken a rest break and were ready to proceed. Before they began the experiment, they were offered an opportunity to ask questions about the procedure, and were reminded once more of the importance of maintaining central fixation.

Results

For each of the two conditions, mean RTs as a function of SOA and cue validity are presented in Table 3-1 and illustrated in Figure 3-2. Looking at Figure 3-2, one can see that RT was faster in the 1-object condition than in the 2-object condition, that in both conditions RT was shorter overall at the cued than at the uncued location, and that as SOA lengthened RT became shorter (a classic foreperiod effect (Bertelson, 1967; Mowrer, 1940)). As indicated below, these observations were confirmed by an analysis of variance

(ANOVA) that included cue validity (cued, uncued) and SOA (105, 300, 600, 1005 ms) as within-subject factors, and condition (1-object, 2-object) as a between-subjects factor.[1]

Our 2-within, 1-between ANOVA revealed that there was a significant main effect for condition [F (1, 46) = 39.77, $p < 0.0001$], reflecting the fact that participants in the 1-object condition were faster to respond than those in the 2-object condition, presumably because the 2-object condition required a target shape discrimination rather than the detection of the onset of a single object, and thus more stimulus information must be acquired in the 2-object condition. The results of the ANOVA also confirmed that there were significant main effects for both cue validity [F (1, 46) = 51.02, $p < 0.0001$] and SOA [F (3, 46) = 178.04, $p < 0.0001$], with RT faster on cued than on uncued trials, and with RT decreasing as SOA lengthened (the foreperiod effect). No interactions were significant [all F's < 2.5]; in particular, it is important to note that the condition x cue validity interaction did not approach significance [F (1, 46) = 1.18, $p > 0.25$].

To confirm that the gaze cuing effect was present in the 2-object condition, a separate ANOVA was conducted on 2-object RTs, with cue validity (valid, invalid) and SOA (105, 300, 600, 1005 ms) as within-subject factors. There were again significant main effects for both cue validity [F (1, 23) = 14.12, $p < 0.001$] and SOA [F (3, 23) = 123.57, $p < 0.0001$], and there was no significant cue validity x SOA interaction [$F < 0.50$].

Anticipations (RTs < 100 ms), keypress selection errors, timed-out trials, and RTs > 1000 ms were classified as errors and were excluded from analysis. Error data are shown in Table 3-1. For each of the 1-object and 2-object conditions, each type of error accounted for less than 1.0% of the target trials; therefore errors were not analyzed further. Catch trials were also excluded from the analysis. In the 1-object condition the false alarm rate on catch trials was 2.22%, and in the 2-object condition the false alarm rate on catch trials was 10.76%. The higher false alarm rate in the 2-object condition probably reflects the fact that catch trials in the 1-object condition involved the presentation of no stimulus, whereas catch trials in the 2-object condition involved the presentation of nontarget stimuli. Previous research has demonstrated that error rates can be greater when catch trials involve a nontarget onset stimulus rather than no target at all (Posner, Snyder, & Davidson, 1980.)

Discussion

In the present study, adult participants fixated on a schematic face that gazed nonpredictively to the left, to the right, or straight ahead. In the 1-object condition, the subsequent target event was a single sudden onset to the left or to the right of the face. In the 2-object condition, the onset of the target to the left or right was accompanied by the onset of a distractor on the other side of the screen. In both conditions, RT was facilitated for targets appearing at a cued (gazed-at) location versus an uncued location.

The RT facilitation for gazed-at targets observed in the 1-object condition replicates the results of several recent studies that have examined the attentional effects of nonpredictive gaze direction (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999).[2] This advantage for gazed-at target locations has been thought to reflect a type of gaze-triggered attentional orienting that is reflexive in nature, because it emerges rapidly and because it occurs even when gaze direction is not predictive of target location. However, as discussed in the introduction to this article, a very plausible alternative explanation for these results is that gaze direction is not actually causing a reflexive shift of attention, but rather that gaze is modulating attentional capture caused by the sudden appearance of the target.

The 2-object condition of the present study rules out such an explanation. In our 2-object condition there was always a sudden onset on the nontarget side of the screen to balance out the onset of the target, and therefore there was no possibility of target-driven exogenous orienting on one side of the screen or the other. And yet, in the 2-object condition we observed reliable RT facilitation for targets appearing at the gazed-at location, an effect that was equivalent to that observed in the 1-object condition. This result demonstrates unequivocally that facilitation for gazed-at targets cannot be attributed to the modulation by gaze of reflexive orienting to the abrupt appearance of the target.

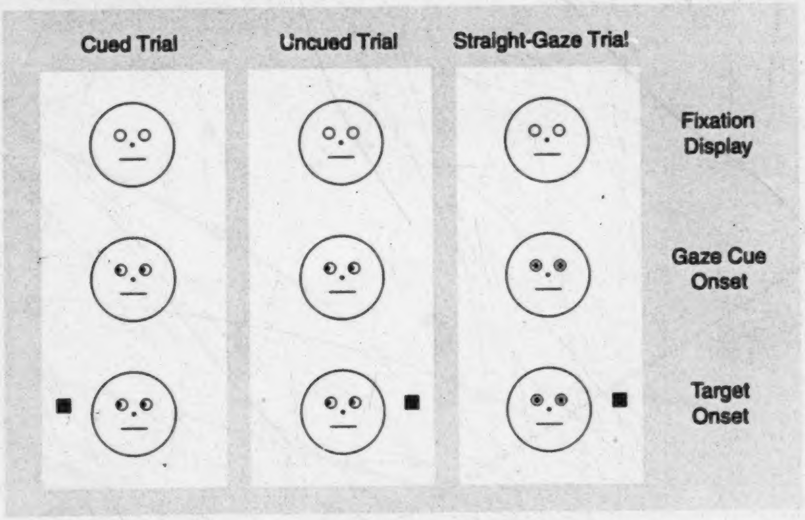
Moreover, because in the 2-object condition there was no possibility of attentional capture by a single abrupt onset on one side of the screen or the other, any benefits for gazed-at target locations can be attributed solely to the attentional effects of the gaze cue. Thus, our finding that the cuing effect was the same for the 1-object and 2-object conditions confirms that the "unusual" aspects of the gaze cuing effect observed in previous studies (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999) and replicated in the present study are clearly attentional in nature. That is, gaze-triggered orienting emerges early and persists much longer than reflexive orienting triggered by peripheral onsets, and it does not give rise to IOR at the gazed-at location. This finding strongly suggests that nonpredictive gaze direction produces a unique type of reflexive orienting with its own distinct time course.

Endnotes

[1] Straight-gaze trials were not included in the analysis because we were primarily interested in obtaining clear evidence of whether a gaze cuing effect (i.e., a difference between cued and uncued RT) would be observed in the two conditions. However it is worth noting that the overall pattern of cued and uncued RTs relative to straight-gaze RTs illustrated in Figure 2 is consistent with that observed previously (Friesen & Kingstone, 1998); i.e., in general, RT appears to be facilitated on cued trials relative to both uncued and straight-gaze trials, with no difference between the latter two.

[2] It should be noted that an apparent difference between the results of the present study and previous studies of nonpredictive gaze direction is that in previous studies the gaze effect had disappeared by approximately 1000 ms (Friesen & Kingstone, 1998; Langton & Bruce, 1999), whereas in the present study the effect appeared to persist at the 1005 ms SOA. While we don't know the reason for this discrepancy, one possibility is that 1000 ms SOA is near the boundary at which the effect disappears.

1-Object Condition


Cued Trial
Uncued Trial
Straight-Gaze Trial
Fixation Display
Gaze Cue Onset
Target Onset

2-Object Condition

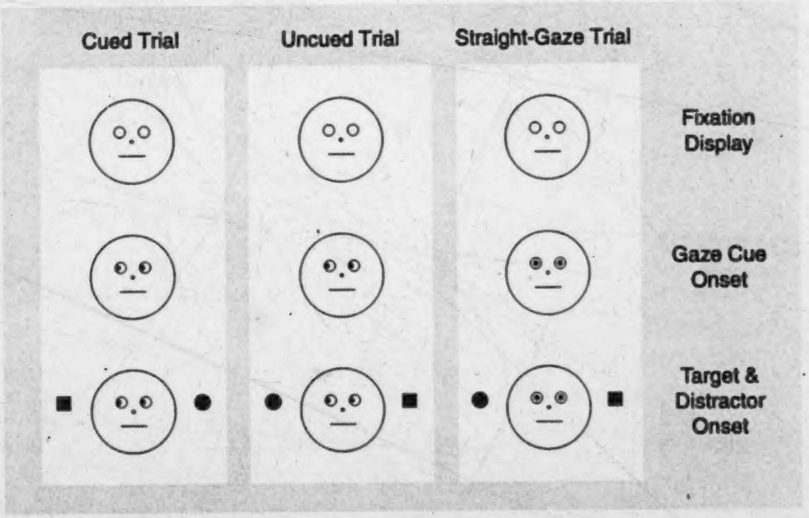

Cued Trial
Uncued Trial
Straight-Gaze Trial
Fixation Display
Gaze Cue Onset
Target & Distractor Onset

Figure 3-1. Illustration of stimuli and examples of cued, uncued, and straight-gaze trial sequences for the 1-object condition and the 2-object condition. Each trial began with a fixation display of a face with blank eyes. After 675 ms, pupils appeared in the eyes looking left, right, or straight ahead (the gaze cue). Then, after 105, 300, 600, or 1005 ms a shape (the target) appeared to the left or the right of the face. In the 1-object condition the target was the only abrupt onset following the cue. In the 2-object condition, a distractor shape appeared on the opposite side of the face at the same time as the target appeared. In these examples, the target is a square (1- and 2-object conditions) and the distractor is a circle (2-object condition).

Table 3-1. Mean Response Times (in Milliseconds), Standard Deviations, and Error Rates (%) for the Two Conditions

	1-Object Condition			2-Object Condition		
	M	SD	%E	M	SD	%E
105 ms SOA						
cued	355	46	0.73	437	48	0.42
uncued	362	43	0.52	449	54	0.42
straight-gaze	359	40	0.21	447	53	0.42
300 ms SOA						
cued	323	36	0.94	407	46	0.10
uncued	342	36	1.35	414	48	0.31
straight-gaze	333	39	0.94	410	54	0.31
600 ms SOA						
cued	306	33	0.83	384	48	0.00
uncued	317	35	0.31	392	49	0.21
straight-gaze	315	34	1.67	395	52	0.31
1005 ms SOA						
cued	314	34	0.94	386	52	0.21
uncued	324	40	1.25	394	57	0.73
straight-gaze	333	41	1.25	395	51	0.83

Note. Error rates represent the percentage of target trials excluded as anticipations, key press selection errors, timed-out trials, or RT > 1000 ms.

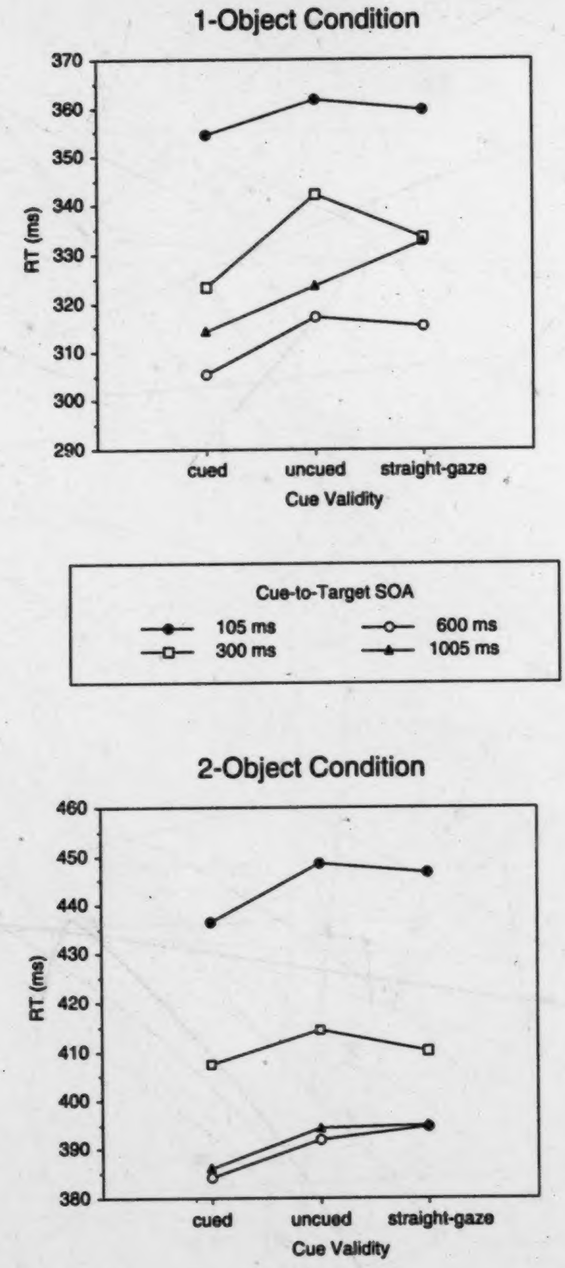


Figure 3-2. Mean response times (RTs) in milliseconds (ms) as a function of cue-to-target stimulus onset asynchrony (SOA) and cue validity for the 1-object and 2-object conditions. Note that RT is greater overall in the 2-object condition.

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Chapter 4

Reflexive and volitional orienting to directional cues: Separable attention effects unique to biologically relevant gaze stimuli

A version of this chapter is under review with the Journal of Experimental Psychology: Human Perception and Performance.

Introduction

Recent behavioral studies with healthy adults have indicated that the tendency to move attention to where someone else is looking is so fundamental that people will attend automatically to a location gazed at by a face on a computer screen, even when gaze direction does not predict where an item may appear (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). A subsequent study by Kingstone, Friesen and Gazzaniga (2000) has revealed that this effect is lateralized to the hemisphere specialized for processing face and gaze information. These findings, coupled with the observation that gaze direction can convey a wide variety of important social signals (for a review, see Langton, Watt, & Bruce, 2000), have led to the suggestion that orienting to gaze direction may represent a unique form of attention involving a specialized system dedicated to biologically relevant directional cues. The present study investigated this hypothesis by examining attentional orienting to directional stimuli that were either biologically relevant or irrelevant.

Friesen and Kingstone (1998) reported that when a schematic face was presented in the center of a computer screen and the eyes of the face served as a nonpredictive cue by gazing to the left or the right, adults were faster to detect, localize, and identify a target stimulus if the target appeared at the gazed-at location. This response time (RT) facilitation effect appeared at a short cue-target stimulus onset asynchrony (SOA) of 100 milliseconds (ms), persisted at SOAs of 300 and 600 ms, and disappeared by a 1000 ms SOA. Both the rapid onset of the facilitation effect, and the fact that it occurred in response to a nonpredictive stimulus, are hallmarks of reflexive attentional orienting (Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Jonides, 1981). This suggested to Friesen and Kingstone that they were measuring a reflexive attentional phenomenon. However, they also noted that orienting to gaze direction did not exhibit all the characteristics normally associated with reflexive shifts of attention. First, the attentional shift to a peripheral target location was triggered by a spatially nonpredictive stimulus (the eyes) that was presented at central fixation. Typically reflexive orienting is produced by presenting a spatially nonpredictive cue (such as the brightening of a box) at a peripheral location where a target might appear (e.g., Posner & Cohen, 1984; Posner, Cohen, & Rafal, 1982). Second, orienting to gaze direction persisted well beyond a cue-target stimulus onset asynchrony (SOA) of 500 ms. Normally the reflexive orienting effect produced by nonpredictive peripheral cues has disappeared when the cue-target SOA exceeds 300 ms (Klein, Kingstone & Pontefract, 1998). Finally, when the facilitatory effect of gaze direction disappeared, it was never replaced by inhibition of return (IOR), an increase in RT for targets appearing at the cued (gazed-at) location. With nonpredictive peripheral cues, the short-lived early facilitation effect at the cued location is typically followed by IOR at longer SOAs (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughn, 1985; for a review, see Klein 2000). These differences suggested to Friesen and Kingstone that attention to gaze direction might represent a unique type of reflexive orienting.

Similar observations of reflexive orienting in response to spatially nonpredictive gaze cues were reported by Langton and Bruce (1999) and Driver et al. (1999). Each of these two studies also examined voluntary orienting to gaze direction by adding predictive meaning to the gaze cue. Langton and Bruce (1999; Experiment 3) examined volitional orienting by making the target likely to appear at the location that a face was pointed toward. In this experiment observers were presented with a face in the center of a computer screen. The face could be turned either to the left, to the right, up, or down. Subjects were informed that the target stimulus would appear 75% of the time at the location that the head and eyes were directed toward (the cued location), and 25% of the time at one of the other three uncued target locations. Results indicated that RT was facilitated for targets appearing at the cued location both when the cue-target SOA was short (100 ms) and when it was long (1000 ms). Langton and Bruce suggested that the facilitation observed at the short SOA reflected a reflexive shift of attention to the gazed-at location (because this effect was also observed at the short SOA in their first two experiments with nonpredictive gaze), and that the facilitation effect observed at the long SOA reflected voluntary orienting to the gazed-at location (because the attentional effect had disappeared at this long SOA in their nonpredictive gaze experiments). This account is both reasonable and consistent with the data. However, because eye direction and head direction were confounded in the face cue, it is not clear whether the effects observed by Langton and Bruce are due to eye direction, head direction, or the combination of the two. Moreover, because Langton and Bruce only sampled performance at two temporal extremes -- a short 100 ms SOA at which reflexive orienting is often observed, and a longer 1000 ms SOA at which reflexive orienting is often absent -- their results do not indicate when voluntary orienting in response to the predictive cue emerged, or more specifically, whether this voluntary orienting effect replaces or overlaps with reflexive orienting.

Driver et al. (1999, Experiment 3) tested the reflexivity of orienting to gaze direction by making the gaze cue counterpredictive with respect to where a target was likely to appear. Observers were presented with a face pointed straight ahead but with eyes gazing to the left or right. They were informed that when the eyes looked to the left, the target would appear on the right 80% of the time, and vice versa. RT performance was sampled at 100, 300, and 700 ms cue-target SOAs. No effects of gaze direction were observed at the shortest SOA of 100 ms; however, at the 300 ms SOA, RT was shorter at the location that the eyes were directed toward (where the target was unlikely to appear), and at the 700 ms SOA there was a nonsignificant trend for RT to be shorter at the location opposite to where the eyes were directed (where the target was likely to appear). In keeping with the interpretation of Langton and Bruce (1999), Driver et al. suggested that their results indicated that at the shorter 300 ms SOA attention was committed reflexively to where the eyes were looking, and that at the longer 700 ms SOA participants were trying to shift attention volitionally to the opposite location where the target was likely to appear. Although this is a plausible interpretation of the data, the fact remains that performance was never significantly faster at the nongazed-at (but likely) target location, and therefore the evidence does not provide strong support for the view that the reflexive orienting observed at 300 ms SOA was replaced by volitional orienting at 700 ms SOA. One alternative interpretation is that with counterpredictive gaze cues, the conflict between the attentional effects of gaze direction and the task requirement to shift attention in the opposite direction somehow diminishes or delays volitional orienting. A second alternative explanation is that reflexive orienting to gaze direction and voluntary orienting to the likely target location were both occurring at the 700 ms SOA. If this were the case, the overall result might be to facilitate RT performance at both the gazed-at location (because of reflexive orienting) and at the likely location (because of volitional orienting), thereby reducing or eliminating any significant differences between these two positions. Note that this alternative interpretation is reasonable because both Driver et al.

(1999, Experiments 1 and 2) and Friesen and Kingstone (1998) have demonstrated with nonpredictive cues that reflexive orienting to gaze direction can be observed with cue-target SOAs of up to 600 - 700 ms.

Considering the data from these studies as a whole, it becomes clear that they do not provide a complete picture of reflexive and voluntary orienting in response to central gaze direction cues. The results of Langton and Bruce (1999) with predictive face/gaze cues indicate that participants can orient attention both reflexively and volitionally to face/gaze directional cues. But they do not isolate these effects to gaze cues, and the data do not reveal whether volitional orienting replaces or overlaps with reflexive orienting. Similarly, the findings of Driver et al. (1999) with counterpredictive gaze cues indicate that 300 ms after a gaze cue, attention is oriented reflexively to the gazed-at location, even when participants have an incentive to shift their attention in the direction opposite to where the eyes are looking, suggesting that orienting to gaze direction may be strongly reflexive. And the trend towards a RT advantage for targets appearing at the predicted location at the longer 700 ms SOA suggests that some volitional orienting might have been occurring at this longer SOA. However, for the reasons just discussed, it is equivocal whether the nonsignificant trend for volitional attention effects to emerge at 700 ms simply reflects weak or delayed volitional orienting, or the co-occurrence of reflexive orienting and volitional orienting.

In Experiment 1 of the present study we used counterpredictive gaze cues in an improved design that allowed us to isolate reflexive orienting to a gazed-at location from voluntary orienting to a predicted location, and to timecourse these effects with more precision. In Experiment 2 we examined the attentional effects of counterpredictive arrows, in order to investigate whether the effects obtained with biologically relevant gaze cues are also observed with symbolic biologically irrelevant directional cues.

Experiment 1: Counterpredictive Gaze

In the Driver et al. counterpredictive gaze experiment (1999, Experiment 3), reflexive orienting was observed to gazed-at but unlikely target locations at a short SOA of 300 ms, but clear evidence of a switch to volitional orienting to likely target locations was not observed at the longer SOA of 700 ms. Two possible reasons for the absence of significant volitional orienting were advanced above. One possibility is that when gaze direction is counterpredictive there is an inherent tension between reflexive and volitional orienting, which delays or abolishes volitional orienting to the predicted location. A second possibility is that at an intermediate SOA both forms of orienting might be operating independently, and when performance at the two locations is contrasted there is no significant difference because performance is facilitated by attention at both locations.

Experiment 1 tested these two ideas. In order to explore the first possibility, we extended the range of cue-target intervals to include long SOAs of 1200 and 1800 ms. We reasoned that this would provide ample opportunity for attention to be oriented volitionally to the predicted (but not gazed-at) location, and that at these long SOAs any reflexive tendency to orient towards the gazed-at location should no longer be present. The second possibility was tested by increasing the number of target locations from two to four. In this way, on any given trial there would always be locations that were neither gazed-at nor predicted. These locations would therefore provide a true baseline against which to assess the allocation of reflexive attention to the gazed-at location and volitional attention to the predicted location. We predicted that if reflexive attention to a gazed-at target location and volitional orienting to a likely target location are independent phenomena that overlap in time, RT facilitation would be observed for targets occurring at gazed-at locations and for targets occurring at likely locations at 600 ms SOA, both across subjects and within subjects.

The gaze direction of a centrally presented schematic face served as the cue, and target onset could occur to the left, to the right, above, or below the face. In order to assess any transitions from reflexive orienting to volitional orienting, we measured performance at a short SOA (105 ms) when reflexive orienting is typically observed, at an intermediate SOA (600 ms) when reflexive and volitional effects might both occur, and at two long SOAs (1200 and 1800 ms) when volitional attentional effects should predominate.

Method

Participants

Twelve introductory psychology students reporting normal or corrected-to-normal vision participated in the experiment for course credit. All participants were unaware of the purpose of the experiment. Testing was divided over two sessions of less than one hour each, conducted on separate days.

Apparatus and Stimuli

The experiment was controlled by a 6100 Power Macintosh computer, with stimuli presented on a 14-inch Apple color monitor set to black and white. Response time and accuracy measures were based on keyboard responses.

The face display, shown in Figure 4-1, consisted of a black line drawing of a face presented on a white background. The round face outline subtended 6.8°, and contained two circles representing the eyes, a smaller circle in the center of the monitor representing the nose and serving as the fixation point, and a straight line representing the mouth. The eyes subtended 0.9°, and the center of each eye was located 1.0° to the left or right of the central vertical axis and 0.8° above the central horizontal axis. The nose subtended 0.2°. The mouth was 2.2° in length and was centered 1.3° below the nose. Black filled-in circles appeared within the eyes and represented the pupils. The pupils subtended 0.5°. For the left and right gaze direction cues, the pupils were centered vertically in the eyes, and were just touching either the left or right of the eyes; for the up and down gaze directions, the pupils were centered horizontally in the eyes, and were just touching either the top or bottom of the eyes; and for straight-ahead gaze, the pupils were centered both horizontally and vertically in the eyes.

--------- Insert Figure 4-1 about here ---------

The target stimulus demanding a detection response was a black capital letter F or T measuring 0.75° wide and 1.35° high, and was presented to the left, right, above or below the face. Target letters were centered on either the horizontal or vertical meridian, and the distance between central fixation (the nose) and the center of the target letter was 6.25°.

Design

Cue-target SOA (105, 600, 1200, or 1800 ms), gaze direction (left, right, up, down, or straight), and target identity (F or T) were selected randomly and with equal probability. When gaze direction was left, right, up, or down, the target letter appeared at the location opposite to where the eyes were looking 75% of the time (e.g., if the eyes looked up, the target was most likely to appear below the face). If a target did not appear at the predicted location, target location was selected randomly and with equal probability from among the three remaining alternative positions. When gaze direction was straight, a target was presented at one of the four locations (left, right, above, or below) randomly and with equal probability.

There were four trial types: predicted but not cued (P-NC) trials, in which the target appeared at the predicted location (i.e., at the position opposite to the gazed-at location); not predicted but cued (NP-C) trials, in which the target appeared at the gazed-at location; not predicted and not cued (NP-NC) trials, in which the target appeared in one of the two locations that were neither gazed-at nor predicted; and straight-gaze trials, in which the eyes looked straight ahead and the target could appear at any of the four target locations. Figure 4-2 illustrates the possible target positions for P-NC, NP-C, and NP-NC trial types.

--------- Insert Figure 4-2 about here ---------

The experiment consisted of two sessions, each composed of 20 practice trials followed by 12 blocks of 60 trials, for a total of 1440 test trials. Approximately 8% of the test trials were catch trials randomly selected from the five gaze direction cues.

Procedure

The sequence of events on a target trial is illustrated in Figure 4-1. All trials began with the presentation of a face with blank eyes. After 675 ms, pupils appeared within the eyes, looking left, right, or straight ahead. Then, after 105, 600, 1200 or 1800 ms, a target letter appeared to the left, right, above, or below the face. Both the gazing face and the target letter remained on the screen until a response was made or until 1500 ms had elapsed, whichever came first. RT was measured from the time of target onset. The intertrial interval was 675 ms.

Participants were seated approximately 57 cm from the monitor, and the experimenter ensured that they were centered with respect to the monitor and keyboard. They were told that each trial would begin with a line drawing of a face with blank eyes, that pupils would appear in the eyes to create a face that was looking left, right, up, down, or straight ahead, and that after the appearance of the pupils, a capital letter (either F or T) would typically appear to the left, right, above, or below the face. Participants were instructed to press the spacebar with the index finger of their preferred hand when a letter appeared on the screen. Also, they were told that occasionally there would be trials in which no target appeared, and that on these trials they should not respond, and just wait for the next trial to begin. The experimenter stressed that it was important to maintain fixation on the nose in the center of the face at all times, and to respond to the target letters as quickly and accurately as possible.

Before beginning each session, participants were told that 75% of the time the eyes looked left, right, up, or down, the target letter would appear at the location opposite to where the eyes were looking, and that when the eyes looked straight ahead, the target was equally likely to appear at any of the four possible target locations.

Participants were informed of the number of trials and blocks they would be completing during the session, and they were told how to initiate each new block of trials after they had taken a rest break and were ready to proceed. Before beginning the experiment, they were offered an opportunity to ask questions about the procedure, and were reminded once more of the importance of maintaining central fixation and responding quickly and accurately.

Results

Mean RTs, standard deviations, and error rates for Experiment 1 are presented in Table 4-1. Anticipations (RTs < 100 ms), timed-out trials, incorrect responses, and RTs longer than 1000 ms were classified as errors and were excluded from analysis. Each type of error accounted for less 0.45% of the target trials. The false alarm rate on catch trials was 0.89%. Because these rates were so low and there were no significant differences between conditions, the error and false alarm data were not analyzed further.

--------- Insert Table 4-1 about here ---------

An ANOVA was conducted with SOA (105, 600, 1200, and 1800 ms) and trial type (predicted but not cued (P-NC), not predicted but cued (NP-C), and neither predicted nor cued (NP-NC)) as within-subject factors.[1] Mean RTs for P-NC, NP-C, and NP-NC trials at each SOA are illustrated in Figure 4-3. The ANOVA revealed that there was a significant main effect for SOA [$F(3,11) = 37.25$, $p < 0.0001$], with RT becoming shorter as SOA lengthened (a standard foreperiod effect, Bertelson, 1967; Mowrer, 1940). There was also a significant main effect for trial type [$F(2,11) = 8.19$, $p < 0.005$], with RT shortest on P-NC trials, intermediate on NP-C trials, and longest on NP-NC trials. The SOA x trial type interaction was marginally significant [$F(6,11) = 2.24$, $p < 0.06$]. An inspection of Figure 4-3 suggests that this marginal interaction reflects facilitation for gazed-at target locations at the 105 and 600 ms SOAs, and facilitation for predicted target locations at the 600, 1200, and 1800 ms SOAs. Planned t-tests confirmed these observations.

--------- Insert Figure 4-3 about here ---------

At each SOA we compared: (1) P-NC vs. NP-NC (the effect of volitional orienting to the predicted location); and (2) NP-C vs. NP-NC (the effect of reflexive orienting to the gazed-at location). One-tailed t-tests were used because we expected any differences to be revealed as facilitation for either gazed-at or predicted locations relative to locations that were neither predicted nor cued.

The comparisons of P-NC versus NP-NC indicated that participants were significantly faster to respond to the predicted location at the 600, 1200, and 1800 ms SOAs (600 ms SOA [$t\ (11) = 3.07$, $p < 0.01$]; 1200 ms SOA [$t\ (11) = 3.30$, $p < 0.005$]; 1800 ms SOA [$t\ (11) = 2.87$, $p < 0.01$]), but not at the 105 ms SOA [$t(11) = 0.86$, $p > 0.25$].

The comparisons of NP-C versus NP-NC indicated that subjects were significantly faster to respond to targets appearing at the cued (gazed-at) location at both the 105 ms SOA [$t\ (11) = 2.74$, $p < 0.01$] and at the 600 ms SOA [$t\ (11) = 1.83$, $p < 0.05$]. This effect was not present at either the 1200 ms SOA [$t\ (11) = 0.16$, $p > 0.25$] or the 1800 ms SOA [$t\ (11) = 1.60$, $p > 0.10$].

Discussion

In the present counterpredictive gaze experiment, the use of four possible target locations made it possible to compare performance for targets appearing at a location that was gazed-at but unlikely to contain a target (NP-C) with RTs for targets appearing at a location that was not gazed-at and yet equally unlikely to contain a target (NP-NC). Similarly, our design allowed us to compare RTs for targets appearing at a location that was not gazed-at but likely to contain a target (P-NC) with RTs for targets appearing at a location that was not gazed-at and also not likely to contain a target (NP-NC).

At the 105 ms SOA, responses to targets occurring at a gazed-at and unlikely location (NP-C) were significantly faster than responses to targets occurring at a nongazed-at and unlikely location (NP-NC). This advantage for cued locations relative to locations that were neither predicted nor cued persisted at the 600 ms SOA, and then disappeared by 1200 ms SOA. These findings are consistent with the reflexive effects observed with nonpredictive gaze cues (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999), and they are also consistent with the Driver et al. (1999, Experiment 3) finding that at a short SOA, gaze direction can produce a covert attention shift even when subjects have incentive based on cue predictability to shift attention to some other location.[2]

We also observed clear evidence that subjects can shift attention volitionally to a predicted location when it is not the gazed-at location: responses were reliably faster for predicted (P-NC) locations relative to locations that were neither predicted nor gazed-at (NP-NC) at 600, 1200, and 1800 ms SOA. Our observation of this effect at the 600 ms SOA indicates that counterpredictive gaze does not delay or weaken volitional orienting, as suggested by the results of Driver et al.'s counterpredictive gaze cue experiment (1999, Experiment 3). Rather, it suggests that in Driver et al.'s experiment, significant effects were not observed at 700 ms SOA because both reflexive and volitional orienting were occurring at that cue-target interval, with reflexive attention being directed to the gazed-at location and volitional attention being directed to the predicted location. As a result, when these two locations were directly compared, there was no significant difference between them. Consistent with this notion, a direct comparison between these two locations in the present experiment revealed that at the 600 ms SOA, the two are not statistically different (P-NC vs. NP-C trials at 600 ms SOA [t (11) = 1.24 $p > .20$ (two-tailed)].

In sum, our data indicate that subjects will orient attention to a gazed-at location even though a target is unlikely to appear there, and that they can also orient attention volitionally to a predicted, nongazed-at location. Thus, Experiment 1 replicates the Driver et al. (1999) finding that orienting to a gazed-at location is reflexive in the strong sense that it occurs even when participants are trying to direct their attention to a different location; and it adds the new finding that participants can indeed allocate attention to a nongazed-at location where a target is likely to appear. Importantly, at the intermediate 600 ms SOA, an SOA at which both reflexive orienting to nonpredictive gaze and voluntary orienting to predictive cues are known to occur, we observed RT facilitation for both gazed-at locations and predicted locations relative to locations that were neither cued nor predicted. This finding suggests that both forms of orienting can occur at the same time.

To confirm that these two forms of orienting were occurring at the same time, we looked at our data in three ways. First, we considered the possibility that our overall results might have been produced by some subjects orienting reflexively to gaze direction and not orienting volitionally, while other subjects were orienting volitionally but not orienting reflexively to gaze direction. Five of our twelve subjects showed one effect but not the other (four showed the volitional effect but not the gaze effect, and one showed the gaze effect but not the volitional effect). When these five subjects were removed from the analysis, the gaze effect and the volitional effect at 600 ms SOA both remained significant [both p's < 0.03], disconfirming this account of our results. Second, we inspected individual subjects' RT distributions for P-NC trials and for NP-C trials at the 600 ms SOA to ensure that subjects were not simply orienting exclusively to the gazed-at location on some trials and orienting exclusively to the predicted location on other trials. There was no evidence of bimodality; i.e., there was no indication that a directed gaze cue produced one effect sometimes and a different effect other times. Finally, we explored the possibility that at the 600 ms SOA subjects might have been in transition from one type of orienting to the other. If this were the case, one would expect the reflexive gaze effect to be smaller at 600 ms than at 105 ms, and one would expect the volitional effect to be smaller at 600 ms than at 1200 ms. Therefore, we compared the reflexive effect (NP-NC minus NP-C) at 600 ms SOA with the reflexive effect at 105 ms SOA, and we compared the volitional effect (NP-NC minus P-NC) at 600 ms SOA with the volitional effect at 1200 ms SOA. These comparisons revealed no significant differences [both p's > 0.35]. Taken together, these findings provide converging support for our proposal that subjects were orienting reflexively to the gazed-at location and volitionally to the likely location at the same time.

Experiment 2: Counterpredictive Arrows

The results of Experiment 1 indicate that orienting to gaze direction is reflexive in a strong sense. That is, it occurs despite the fact that gaze direction predicts that a target is likely to appear at a different, nongazed-at location. And it occurs even when attention is being oriented volitionally to the predicted nongazed-at location. Although it seems reasonable to speculate that the results of Experiment 1 are unique to gaze direction, possibly because of its biological relevance for humans living in a social environment, this position remains untested. Indeed, recent evidence suggests that nonpredictive arrow cues can produce RT patterns that look very similar to those produced by nonpredictive gaze direction (Ristic, Friesen & Kingstone, 2001, submitted). The purpose of Experiment 2 was to examine whether similar effects to those observed in Experiment 1 would be observed with a counterpredictive central directional cue that was biologically irrelevant, i.e., an arrow.

Experiment 2 was identical in every way to Experiment 1, except that arrows served as the counterpredictive directional cue.

Method

Participants

Twelve undergraduate students reporting normal or corrected-to-normal vision participated in the experiment for course credit. All participants were unaware of the purposes of the experiment, and none had participated in any previous conditions. Testing was divided over two sessions of less than one hour each, conducted on separate days.

Apparatus and Stimuli

The apparatus used was identical to that used in Experiment 1. Stimuli for Experiment 2 are illustrated in Figure 4-4. The fixation display consisted of a black line drawing of a cross centered within a circle. The circle subtended 6.8° and was centered in the middle of the monitor. The cross within the circle was composed of a horizontal line and a vertical line, each of which was 2.1° in length. The intersection of the two lines of the cross served as the fixation point. Directional cues were provided by an arrow head and an arrow tail appearing at either end of one of the two lines of the cross (i.e., 1.2° from central fixation, as measured from the intersection of the cross to the pointed end of the arrow head or tail). The arrow heads and tails were each composed of two lines 0.6° in length, and measured 0.8° high by 0.5° wide. A nondirectional cue was provided by small lines appearing at the ends of both lines of the cross, such that each arm of the cross ended in a perpendicular line measuring 0.6°. As in Experiment 1, the target stimulus was a black capital letter, either F or T, measuring 0.75° wide and 1.35° high. Target letters were presented 6.25° to the left or right of the center of the cross, as measured from the vertical meridian to the center of the target letter.

--------- Insert Figure 4-4 about here ---------

Design

The experimental design was identical to that of Experiment 1, with the exception that the directional cues were arrows and the nondirectional cue was a cross with perpendicular lines on the end of each arm. Cue to target SOA (105, 600, 1200, or 1800 ms), cue type (left, right, up, or down arrow, or nondirectional cross), and target identity (F or T) were selected randomly and with equal probability. The probabilities of a target appearing at any one of the four locations were the same as in Experiment 1. When the cue was an arrow pointing left, right, up, or down, the target letter appeared at the location opposite to where the arrow was pointing 75% of the time and at one of the other three locations 25% of the time; and when the cue was the nondirectional cross, the target appeared with equal probability at any one of the four locations. Thus, there were four trial types with probabilities identical to those in Experiment 1: predicted but not cued (P-NC) trials; not predicted but cued (NP-C) trials; not predicted and not cued (NP-NC) trials; and nondirectional cross trials. Approximately 8% of the trials were catch trials randomly selected from the five cue types.

As was the case with Experiment 1, Experiment 2 consisted of two sessions, each composed of 20 practice trials followed by 12 blocks of 60 trials, for a total of 1440 test trials.

Procedure

Figure 4-4 provides an illustration of the sequence of events on a test trial. The start of each trial was signaled by the presentation of a cross positioned within a circle. After 675 ms, either an arrow head and tail appeared on one of the lines of the cross, creating an arrow that pointed left, right, up, or down; or a small line appeared at the end of each arm of the cross to create the nondirectional cue. After 100, 600, 1200, or 1800 ms, a target letter (F or T) appeared at one of the four target locations (left, right, up, or down). Both the cue and the target remained on the screen until a response was made or 1500 ms had elapsed, whichever came first.

The instructions mirrored those of Experiment 1. Participants were instructed to maintain fixation on the intersection of the lines of the cross, and to respond to the target as quickly and accurately as possible.

Results

Mean RTs, standard deviations, and error rates for Experiment 2 are presented in Table 4-2. Anticipations (RTs < 100 ms), timed-out trials, incorrect responses, and RTs longer than 1000 ms were classified as errors and were excluded from analysis. Each type of error accounted for less than 0.25% of the target trials. The false alarm rate on catch trials was 1.48%. Because these rates were so low and there were no significant differences between conditions, the error and false alarm data were not analyzed further.

--------- Insert Table 4-2 about here ---------

An ANOVA was conducted with SOA (105, 600, 1200, and 1800 ms) and trial type (predicted but not cued (P-NC), not predicted but cued (NP-C), and neither predicted nor cued (NP-NC)) as within-subject factors. Figure 4-5 illustrates RTs for P-NC, NP-C, and NP-NC trials. As in Experiment 1, there was a significant main effect for SOA [$F(3,11) = 16.02$, $p < 0.0001$], reflecting a foreperiod effect. The main effect for trial type was also significant [$F(2,11) = 11.65$ $p < 0.001$], with RTs on P-NC trials shorter than RTs on NP-C and NP-NC trials. The SOA x trial type interaction was not significant [$F(6,11) = 1.51$, $p > 0.18$].

--------- Insert Figure 4-5 about here ---------

As with Experiment 1, planned contrasts (one-tailed t-tests) were conducted at each SOA to compare: (1) RTs for targets occurring at a predicted location (P-NC trials) against RTs for targets occurring at a location that was neither predicted nor cued (NP-NC trials); and (2) RTs for targets occurring at a cued location (NP-C trials) against RTs for targets occurring at a location that was neither predicted nor cued (NP-NC trials).

The comparisons of P-NC versus NP-NC indicated that subjects were not faster to respond to the predicted location at the 105 ms SOA [$t (11) = 1.06$ $p > 0.10$], but that they were faster to respond to the predicted location at the 600, 1200, and 1800 ms SOAs (600 ms SOA [$t (11) = 3.18$ $p < 0.005$]; 1200 ms SOA [$t (11) = 3.96$, $p < 0.005$]; 1800 ms SOA [$t = 1.90$, $p < 0.05$]).

The comparisons of NP-C versus NP-NC indicated that subjects were never significantly faster to respond to targets appearing at the cued location (i.e., the location towards which the arrow pointed) [all t's < 1.07 , all p's > 0.10].

Discussion

Experiment 2 was identical to Experiment 1, with the exception that arrows were used instead of gaze as the centrally-presented counterpredictive cue. The pattern of RTs for predicted but not cued target locations (P-NC) versus locations that were neither predicted nor cued (NP-NC) was very similar to that obtained with counterpredictive gaze in Experiment 1; that is, an advantage for targets occurring at the predicted location was observed at 600, 1200, and 1800 ms SOA, indicating that participants were able to shift attention volitionally to the location where a target was likely to occur. However, the pattern of RTs for locations that were not predicted but cued (NP-C) versus locations that were neither predicted nor cued (NP-NC) was very different from that obtained in Experiment 1: with arrows, there was never any advantage for targets occurring at the cued location. Together these data indicate that reflexive orienting to gaze direction is unique in producing a strongly reflexive shift of attention, possibly due to the fact that, unlike arrows, gaze direction is a biologically relevant social cue (Langton, Watt & Bruce, 2000).

General Discussion

Our counterpredictive gaze experiment (Experiment 1) replicated the finding of Driver et al. (1999) that subjects orient attention reflexively to a gazed-at location at a short SOA even though they expect the target not to appear there. This confirms that orienting to gaze direction is reflexive in a strong sense, i.e., that it can occur even against subjects' intentions. Experiment 1 also demonstrated that subjects can direct attention volitionally to a nongazed-at location at longer SOAs. Moreover, this experiment revealed that at an intermediate SOA, when both reflexive attention to the gazed-at location and voluntary attention to the likely location might be expected to occur, both did indeed occur. In other words, reflexive orienting to gazed-at locations and volitional orienting to likely locations exhibited different but overlapping time courses. This suggests that gaze-triggered orienting and volitional orienting are independent.

The results of our second experiment with counterpredictive arrows suggest that the data pattern observed in Experiment 1 is unique to biologically relevant gaze direction cues. Experiment 2 was identical in every way to Experiment 1 with the exception that gaze direction cues were substituted with arrow cues. Yet the results were clearly very different. In both experiments, evidence of voluntary orienting to the predicted target location was observed at 600, 1200, and 1800 ms SOA. However, with counterpredictive arrow cues, there was no evidence of orienting to the cued location, in contrast to our findings with counterpredictive gaze cues. This difference lends support to the notion that gaze direction may be a special attentional cue that can, by virtue of its social significance, trigger reflexive shifts of attention that are in opposition to, and concurrent with, volitional shifts of attention.

The co-occurrence of reflexive orienting to the gazed-at location and volitional orienting to likely target location observed in Experiment 1 suggests that the two forms of orienting are independent, and thus that they may be subserved by different attentional systems or subsystems. There is considerable evidence in the attentional literature indicating that reflexive orienting to a sudden onset at a peripheral location and volitional orienting to an expected target location occur by way of different brain pathways. Reflexive orienting to a sudden onset in the periphery is thought to involve the superior colliculus (SC), working in concert with parietal cortex (Rafal, Henik, & Smith, 1991; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988), whereas volitional orienting to an expected target location is thought to involve frontal and parietal areas (Corbetta, Miezin, Shulman, & Petersen, 1993; Posner 1995; Posner and Raichle, 1994). It seems likely, however, that reflexive orienting triggered by gaze direction does not occur by way of either of these pathways.

Several lines of evidence suggest that gaze-triggered orienting does not occur by way of the subcortical pathway. First, in their study with split-brain patients, Kingstone, Friesen, and Gazzaniga (2000) demonstrated that reflexive orienting to gaze direction is lateralized to one cortical hemisphere. Second, in a recent eye movement study, Friesen and Kingstone (2001b, manuscript in preparation) found that the effect of removing the fixation stimulus at the time of target onset (an effect known to disinhibit the subcortical SC) was not modulated by gaze direction. And third, Friesen and

Kingstone (2001a, submitted) demonstrated that reflexive orienting to gaze direction can co-occur with IOR (which is subserved by the SC).

Similarly, the finding of the present study that reflexive orienting to a gazed-at location and volitional orienting to a different location can co-occur suggests that attention to gaze does not occur by way of the frontal-parietal pathway that underlies volitional orienting. This conclusion is consistent with two other results suggesting that gaze-triggered orienting is not simply a "well-greased" form of volitional orienting: (1) Ristic, Friesen, and Kingstone (2001, submitted) found that preschool children showed greater orienting effects than adults in response to nonpredictive gaze direction cues, despite the fact that young children are known to be poor at volitional orienting (Brodeur, Trick, and Enns, 1997); and (2) In their split-brain patient study, Kingstone, Friesen, and Gazzaniga (2000) found that although only the cortical hemisphere specialized for face and gaze processing oriented reflexively in response to nonpredictive gaze cues, both hemispheres oriented volitionally in response to predictive gaze cues.

So what might the gaze-triggered reflexive attention pathway be? Kingstone, Friesen, and Gazzaniga (2000) proposed that orienting to gaze direction might be subserved by a temporal-parietal pathway, with cells in inferotemporal cortex (IT) processing face and gaze information, cells in the superior temporal sulcus (STS) processing the direction of gaze, and cells in parietal cortex shifting attention to the gazed-at location. Note that all three proposed attentional pathways -- the subcortical reflexive pathway, the cortical volitional pathway, and the cortical gaze direction pathway -- involve parietal cortex. How, then, could attention be shifted reflexively to a gazed-at location and volitionally to a different location at the same time? One possibility is that volitional inputs from frontal cortex and gaze inputs from temporal cortex activate different parietal neurons. In a recent fMRI study that compared peripheral target detection versus volitional orienting, Corbetta et al. (2000) found evidence for this type of dissociation, with temperoparietal cortex activated during target detection, and intraparietal cortex activated during volitional orienting.

To our knowledge, the present study is the first to demonstrate that gaze cues and arrow cues can produce qualitatively different behavioural results in intact observers. In their recent study with nonpredictive gaze and arrow cues, Ristic, Friesen, and Kingstone (2001, submitted) found that nonpredictive gaze cues and nonpredictive arrow cues produced similar RT patterns in normal participants (both adults and children). Differences in the effects of the two types of directional cue were revealed only when the performance of a split-brain patient was examined. Nonpredictive arrow cues triggered orienting in both hemispheres, whereas in a previous study of the same patient nonpredictive gaze cues triggered orienting only in the hemisphere specialized for face processing (Kingstone, Friesen, and Gazzaniga, 2000). Based on this difference in lateralization for the two cue types, Ristic, Friesen, and Kingstone concluded that gaze, as a biologically relevant cue, is indeed special. The present study, however, demonstrates that apart from the issue of lateralization of face processing, gaze and arrow cues can trigger qualitatively different behavioral effects. When each of these directional cues is put into competition with volitional orienting, reflexive orienting to gaze direction persists, whereas reflexive orienting to arrows is abolished. The strong implication is that the network of neural activation subserving reflexive orienting to gaze direction is distinct from the neural systems subserving volitional orienting, and that this separation is unique to a biologically relevant stimulus such as gaze direction.

In sum, the results of the present study confirm that attentional orienting toward a gazed-at location is reflexive, not only in the sense that it occurs when participants do not have any incentive to attend to the gazed-at location (as is the case in nonpredictive gaze experiments), but also in the stronger sense that it can occur even when participants are attending volitionally to an opposite location. This finding that reflexive and volitional orienting in response to gaze direction can co-occur suggests that the two may be subserved by distinct and separable mechanisms. And finally, the difference we observed between the effects of counterpredictive gaze cues and counterpredictive arrow cues suggests that orienting to gaze direction may represent a unique form of reflexive orienting that is specific to biologically relevant directional cues.

Endnotes

[1] In a previous study (Friesen & Kingstone, 1998) we treated straight-ahead gaze trials as neutral trials, against which costs and benefits could be assessed. This seemed reasonable in a series of experiments in which eye direction was never predictive. However, there are problems with treating eyes straight ahead as neutral once averted gaze direction is given predictive meaning -- now some eyes have predictive meaning, and some do not. Thus, in the current study, the critical comparisons are always between trials in which the cue is directed towards one of the possible target locations.

[2] Although we did not monitor subjects' eye movements in the present study, we are confident that eye movements were not involved in producing our cuing effects. It is well known that for simple detection tasks subjects will spontaneously avoid making eye movements to the target (Posner, 1980). Moreover, the fact that in Experiment 1 at the 600 ms SOA RT was facilitated at two target locations on opposite sides of the central cue (i.e., P-NC and NP-C locations) strongly suggests that participants were maintaining central fixation. And the fact that the facilitation effect on P-NC trials at 1200 and 1800 ms SOA was similar to that at 600 ms SOA suggests that participants were continuing to maintain fixation at the longer SOAs.

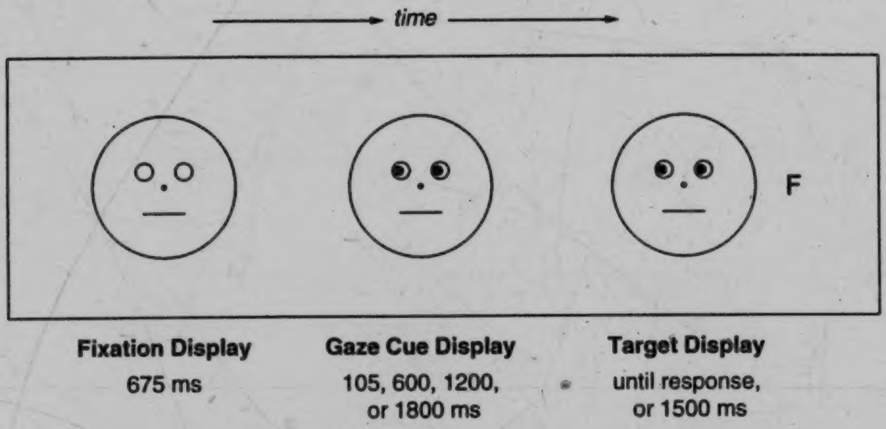
time
F
Fixation Display
675 ms
Gaze Cue Display
105, 600, 1200, or 1800 ms
Target Display
until response, or 1500 ms

Figure 4-1. Illustration of the trial sequence in Experiment 1. Each trial began with the presentation of a face with blank eyes. After 675 ms, pupils appeared in the eyes, looking left, right, up, down, or straight ahead (the gaze cue). Then, after 105, 600, 1200, or 1800 milliseconds (ms), the letter F or T (the target) appeared to the left or to the right, above, or below the face. The target was likely to appear at the location opposite to the gazed-at location 75% of the time the eyes looked left, right, up, or down.

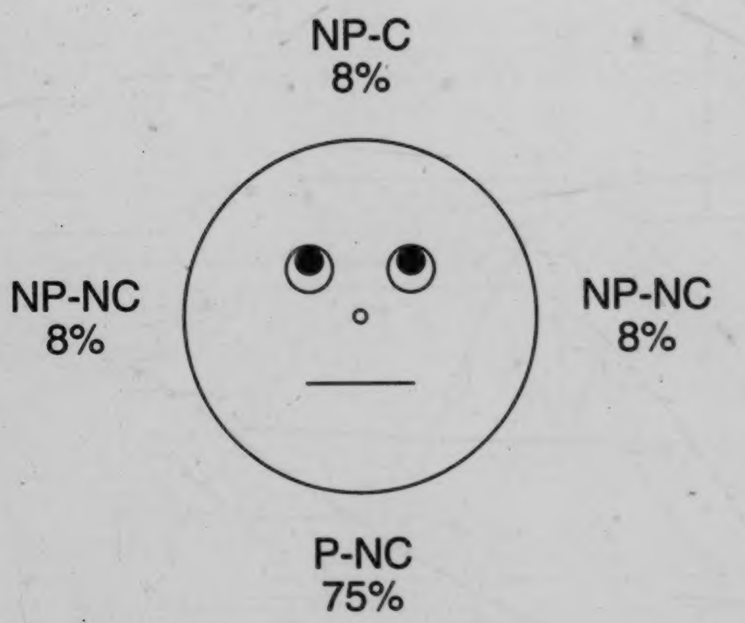

Figure 4-2. Illustration of the three trial types that were possible when gaze was directed at one of the four target locations in Experiment 1. P-NC = target occurs at the predicted (not cued by gaze direction) location. NP-C = target occurs at the cued (not predicted) location. NP-NC = target occurs at a location that is neither predicted nor cued. Numbers represent the percent probability (rounded to the nearest percentage point) of the target's appearance at each location.

Table 4-1. Mean RTs (in ms), Standard Deviations, and Errors Rates (%) for Experiment 1

		M	SD	%E
105 ms SOA				
	P-NC	384	59	0.98
	NP-C	370	56	0.77
	NP-NC	386	67	0.95
	straight gaze	383	67	0.50
600 ms SOA				
	P-NC	346	58	0.84
	NP-C	347	50	0.00
	NP-NC	366	65	2.12
	straight gaze	354	51	0.62
1200 ms SOA				
	P-NC	329	54	0.67
	NP-C	349	61	0.38
	NP-NC	355	61	0.91
	straight gaze	339	50	1.02
1800 ms SOA				
	P-NC	337	48	0.55
	NP-C	347	61	0.79
	NP-NC	352	53	0.38
	straight gaze	349	51	0.25

Note. Error rates represent the percentage of test trials from each cell excluded as anticipations, key press selection errors, timed-out trials, or trials with RT > 1000 ms. SOA, stimulus onset asynchrony.

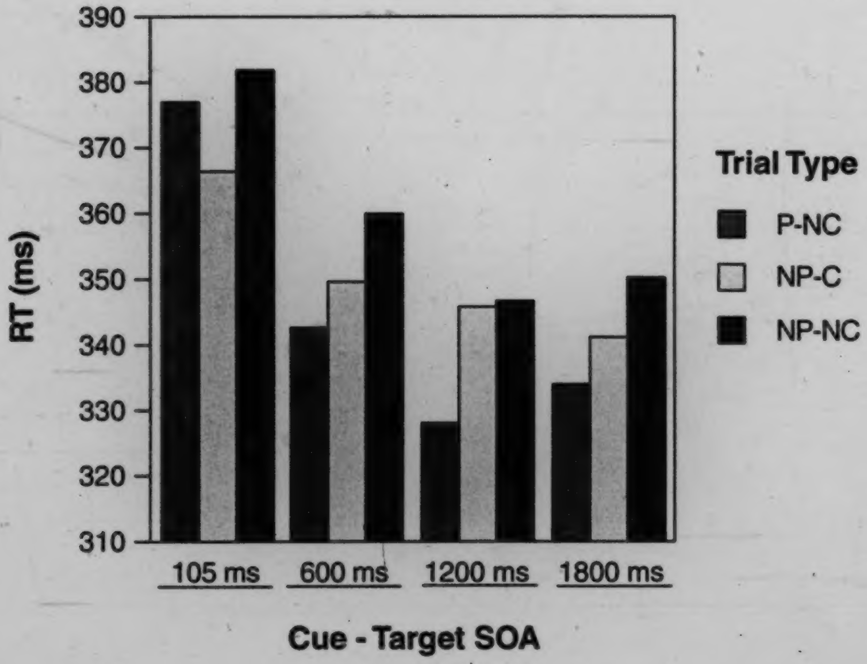

Figure 4-3. Experiment 1 mean RTs for counterpredictive gaze cues as a function of cue-target stimulus onset asynchrony (SOA) and trial type. P-NC = target occurs at the predicted (not cued) location. NP-C = target occurs at the cued (not predicted) location. NP-NC = target occurs at a location that is neither predicted nor cued.

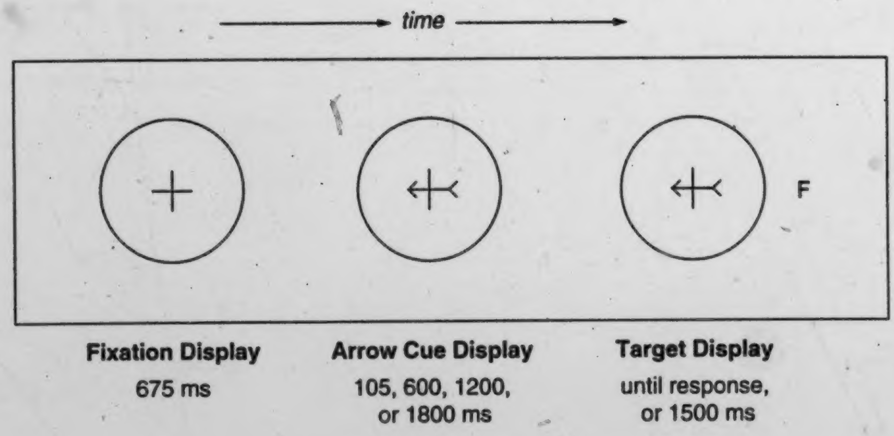
time
F
Fixation Display
675 ms
Arrow Cue Display
105, 600, 1200,
or 1800 ms
Target Display
until response,
or 1500 ms

Figure 4-4. Illustration of the trial sequence in Experiment 2. Each trial began with a cross at central fixation. After 675 milliseconds (ms), an arrow head and an arrow tail appeared on one of the two lines of the cross, creating an arrow pointing left, right, up, or down. On nondirectional cross trials, small perpendicular lines appeared at the ends of the lines of the cross. Then, after 105, 600, 1200, or 1800 ms, a target letter (F or T) appeared to the left, to the right, above or below the cross. Trial types and probabilities were the same as those for counterpredictive gaze direction cues (see Figure 4-2).

Table 4-2. Mean RTs (in ms), Standard Deviations, and Errors Rates (%) for Experiment 2

		M	SD	%E
105 ms SOA	P-NC	368	55	0.46
	NP-C	369	60	0.79
	NP-NC	375	55	0.38
	cross	387	56	0.77
600 ms SOA	P-NC	335	56	0.72
	NP-C	352	59	0.00
	NP-NC	353	44	0.19
	cross	350	45	0.00
1200 ms SOA	P-NC	320	54	0.42
	NP-C	337	52	0.37
	NP-NC	343	46	0.36
	cross	338	52	0.37
1800 ms SOA	P-NC	328	55	0.58
	NP-C	345	52	0.39
	NP-NC	340	51	0.75
	cross	342	54	0.38

Note. Error rates represent the percentage of test trials from each cell excluded as anticipations, key press selection errors, timed-out trials, or trials with RT > 1000 ms. SOA, stimulus onset asynchrony.

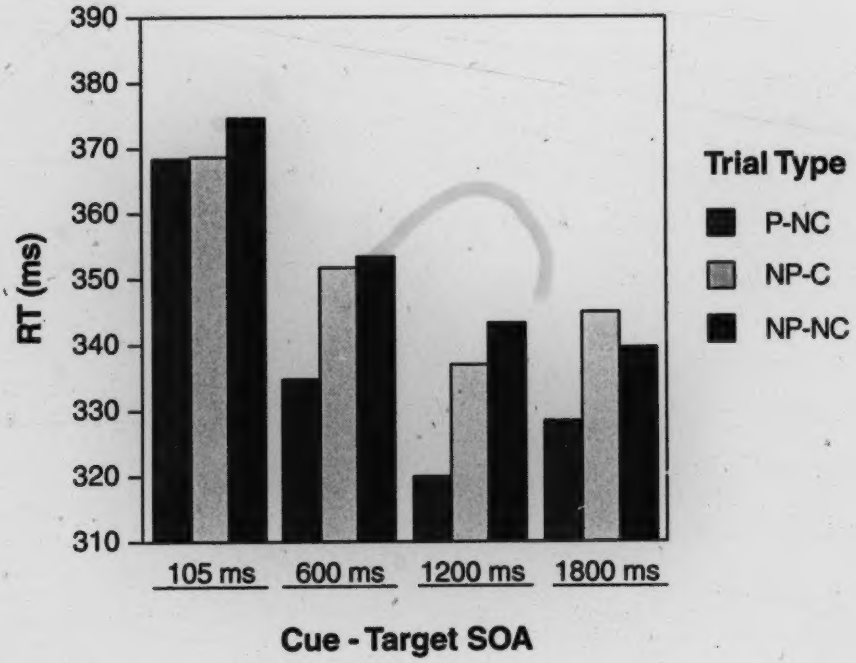

Figure 4-5. Experiment 2 mean RTs for counterpredictive arrow cues as a function of cue-target stimulus onset asynchrony (SOA) and trial type. P-NC = target occurs at the predicted (not cued) location. NP-C = target occurs at the cued (not predicted) location. NP-NC = target occurs at a location that is neither predicted nor cued.

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Chapter 5

Abrupt Onsets and the Gaze Direction of a Schematic Face Produce Independent Reflexive Effects

A version of this chapter is under revision for resubmission to Psychonomic Bulletin and Review.

Introduction

Three recent attentional studies reported that adults respond more quickly to targets if they appear at a location gazed at by a centrally presented stimulus face than if targets appear at a location that gaze is not directed towards (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). In all three studies, this gaze direction effect exhibited some of the standard characteristics of reflexive covert attention (Cheal & Lyon, 1991; Müller & Rabbitt, 1989; Jonides, 1981): it emerged rapidly, occurring as early as 100 milliseconds (ms) after the appearance of the gaze stimulus; it occurred even though subjects were informed that gaze direction did not predict target location; and it exhibited a relatively short time course, disappearing approximately one second after the onset of the gaze stimulus.

However, there are also some important differences between the reports of reflexive orienting to gaze direction and previous reports of reflexive covert orienting in the literature. First and foremost is the fact that in the gaze studies, reflexive orienting was triggered by a nonpredictive cue that appeared at central fixation. Typically reflexive orienting is produced by a nonpredictive object appearing abruptly in a parafoveal location (called a "peripheral cue"; Posner, 1980; Posner, Cohen, & Rafal, 1982). Second, traditional studies of reflexive orienting report that when the cue-target stimulus onset asynchrony (SOA) is greater than 300 ms, response time (RT) is longer for a target that appears at the location of the peripheral cue than at a different (uncued) location. This delay in RT is generally attributed to attention being drawn initially to the location of the peripheral cue, and then removed; when a target later appears at the cued location, the return of attention to the cued location is inhibited (Posner & Cohen, 1984). Accordingly this RT delay for targets that appear at a previously cued/attended location has been called the "inhibition of return" (IOR) phenomenon (Posner, Rafal, Choate, & Vaughn, 1985).

Importantly, no evidence of IOR has been observed in the nonpredictive gaze direction studies; that is, RT has never been found to be longer for targets appearing at the cued (gazed-at) location compared to an uncued (not gazed-at) location (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). If a single spatial orienting system controls reflexive shifts of attention to locations in space and IOR to previously attended locations, then one would expect that gaze cues would produce IOR just as peripheral cues do. Thus, the absence of an IOR effect in the gaze studies reported to date suggests that reflexive orienting triggered by gaze direction may be a qualitatively different type of reflexive orienting from reflexive orienting to peripheral onsets. This view is consistent with emerging evidence that cortical mechanisms play a dominant role in attention to gaze direction (Kingstone, Friesen, & Gazzaniga, 2000), whereas subcortical mechanisms, specifically the superior colliculus, are involved in reflexive orienting and IOR to peripherally cued locations (Rafal, Henik, & Smith, 1991; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). However, the apparent absence of IOR in the gaze studies -- effectively a null result -- is negative evidence; it does not provide compelling evidence that attention to gaze direction and the IOR effect are independent phenomena.

The goal of the present study was to test the independence of these two reflexive attentional phenomena. We reasoned that if orienting to gaze direction and the IOR effect are independent of one another and are subserved by different brain mechanisms, it should be possible to elicit reflexive attention to a gazed-at location and IOR to an abrupt onset location concurrently. To test this hypothesis we presented participants with four circles surrounding a central fixation point. As illustrated in Figure 5-1, a schematic face abruptly appeared in one of the four circles, with its eyes gazing either at one of the other three circles or straight ahead. Gaze direction did not predict the location of the target stimulus. 105, 555, or 1005 ms after the onset of the gazing face cue, the offset of one of the four circles served as the target. Thus, our design allowed us to probe the gazed-at location, uncued locations, and the location of the gaze cue onset, in order to examine effects of the face stimulus both as a gaze direction cue and as an abrupt onset cue. Of particular interest was performance at the intermediate SOA of 555 ms, because based on previous studies this is an SOA at which both reflexive attention to gaze (e.g., Friesen & Kingstone, 1998) and IOR (for a review, see Klein, 2000) could be expected to occur.

---------- Insert Figure 5-1 about here ----------

We predicted that if orienting to a gaze direction and IOR are independent reflexive attentional effects, then in the present study: (1) directed gaze cues would produce reflexive shifts of attention to a gazed-at location; (2) the abrupt onset of the schematic face would produce IOR at the location of the abrupt onset; (3) directed gaze cues would produce both reflexive attention to a gazed-at location and IOR at the abrupt onset location at the 555 ms SOA; and (4) the magnitude of IOR at the abrupt onset location would not be affected by gaze direction.

Method

Subjects

Eighteen experimentally naive undergraduates participated in the experiment for course credit. All participants reported normal or corrected-to-normal vision.

Apparatus

The experiment was controlled by a 6100 Power Macintosh computer, and stimuli were presented on a 15-inch Apple color monitor set to black and white. Response time (RT) and accuracy measures were based on keyboard responses. Participants were seated approximately 57 cm from the monitor, and were centered with respect to the monitor and keyboard.

Stimuli

The stimuli, illustrated in Figure 1, were presented as black line drawings on a white background. A small fixation circle (0.1° in diameter) appearing in the center of the screen was present throughout each trial. Four peripheral location circles subtending 1.8° surrounded the fixation circle. The distance from the center of each of these circles to the horizontal and vertical meridians was 1.1°. On each trial, two eyes, a nose, and a mouth appeared abruptly within one of the location circles. The nose was a 0.1° circle positioned in the center of the surrounding location circle. The mouth was a straight horizontal line, 0.7° in length and centered 0.4° below the nose. The eyes were represented by two 0.6° circles (the eye outlines) containing 0.3° black filled-in circles (the pupils). The center of each eye outline was 0.4° above the center of the surrounding location circle, and 0.3° to the left or right of the center of the surrounding circle. When the eyes were gazing straight ahead, the pupils were centered within the eye outlines, and when the eyes were gazing at one of the other three circles, the pupils were positioned such that they just touched the edge of the eye outline and looked directly up, down, left, right, or diagonally (45°) towards one of the other circles. The target event demanding a response was the disappearance of one of the four location circles.

Design

The experiment was composed of 668 trials, with a block of 20 practice trials preceding 12 test blocks of 54 trials each. Gaze direction, target offset location, and cue-target stimulus onset asynchrony (SOA) duration were selected randomly within each block. Approximately 11% of the trials were catch trials in which all four location circles remained on the screen.

Figure 1 provides a representative illustration of the display sequence for each type of trial. Gaze was either directed at one of the other three location circles, or straight ahead. The target event was the offset of one of the four location circles either at the gazed-at location, at an uncued location, or at the location of the gazing face onset. Thus, there were five types of cue-target validity which we named according to the combination of gaze cue type (Directed gaze or Straight gaze) and target location (Gazed-at location, Uncued location, or face Onset location). On D-G trials, the face's gaze was Directed at one of the other three circles, and the target event was the disappearance of the circle at the Gazed-at location. On D-U trials, gaze was Directed at one of the other three circles, and the target event was the disappearance of an Uncued circle (i.e., one of the two empty circles that gaze was not directed towards). On D-O trials, gaze was Directed at one of the other three circles, and the target event was the disappearance of the circle at the location of the Onset of the gazing face. On S-U trials, gaze was Straight ahead, and the target event was the disappearance of a circle at one of the Uncued locations (i.e., one of the three empty circles). And finally, on S-O trials, gaze was Straight ahead, and the target event was the disappearance of the circle at the location of the Onset of the gazing face.

In terms of the four predictions outlined above, we expected that (1) on directed gaze trials, a gaze cuing effect would be revealed as shorter RTs for targets occurring at a gazed-at location than for targets occurring at an uncued location (i.e., D-G < D-U); (2) on straight gaze trials, an IOR effect would be revealed as longer RTs for targets occurring at the location of the face onset than for targets occurring at any of the other three locations (i.e., S-O > S-U); (3) if directed gaze cues produced both reflexive attention to a gazed-at location and IOR at the abrupt onset location at the 555 ms SOA, then RTs on directed gaze trials would be longer for targets occurring at the location of the face onset than for targets occurring at an uncued location (i.e., D-O >D-U at 555 ms SOA); and (4) if the magnitude of IOR at 555 ms SOA was not affected by gaze direction, then on trials in which the target occurred at the location of the face onset, RT would be the same whether gaze was directed or straight (i.e., D-O = S-O at 555 ms SOA).

Cue-target SOA, measured from the onset of the gazing face cue to the offset of a location circle, was randomly selected from durations of 105, 555, and 1,005 ms.

Procedure

The start of each trial was signaled by the presentation of the four empty location circles arranged around the central fixation dot. After 675 ms, a face appeared abruptly within one of the four circles, gazing either toward one of the other circles or straight ahead. The target event following this gaze cue was the disappearance of one of the four circles, either the one surrounding the face or one of the three empty circles. The face, the fixation dot, and the three remaining location circles stayed on the screen until a response was made or 1,500 ms had elapsed, whichever came first. The intertrial interval was 675 ms.

The participants' task was to maintain fixation on the central dot and to indicate as quickly and accurately as possible that they had detected the disappearance of one of the four location circles by pressing the space bar on the computer keyboard with the index finger of their preferred hand. On catch trials, in which all location circles remained on the screen, subjects were not to respond.

Before beginning the experiment, participants were told that four empty circles and a fixation dot would appear on the screen signaling the start of each trial, and that it was important that they fixate their eyes on the dot in the center of the screen at all times. Subjects were told that after the appearance of the circles a face would appear in one of the circles, looking either at one of the other three circles or straight ahead, and that after that, one of the four circles could disappear. Participants were informed that the direction in which the eyes looked was not in any way predictive of whether a circle would disappear or which circle would disappear, and they were instructed to respond as quickly and accurately as possible to the disappearance of a circle.

Participants were informed of the number of trials and blocks in the experiment and they were instructed to press the space bar to initiate each new block of trials after they had taken a rest break and were ready to proceed. Before they began the experiment, they were offered an opportunity to ask questions about the procedure, and were reminded once more of the importance of maintaining central fixation.

Results

Catch Trials and Errors

The false alarm rate on catch trials, which were excluded from the analysis, was 1.62%. For each subject, RTs greater or less than 2.0 standard deviations from their cell mean were excluded. These comprised 4.43% of the target trials. Anticipations (RTs < 100 ms) and timed-out trials (no response within 1,500 ms) were classified as errors and were also excluded from the analysis. Error data are presented in Table 1. Overall, anticipations accounted for 0.12% of the target trials, and timed-out trials accounted for 1.13% of the target trials. An ANOVA was conducted on the proportion of anticipations with cue type (directed and straight) as the within-subject factor, and a separate ANOVA was conducted on the proportion of timed-out trials, with trial type (D-G, D-U, D-O, S-U, and S-O) as the within-subject factor. In both cases, analysis of the error rates did not produce a significant effect [both F's < 1].

---------- Insert Table 5-1 about here ----------

Correct Responses

Mean RTs for correct responses on target trials are presented in Table 1 and illustrated in Figure 2. An omnibus ANOVA was conducted with SOA (105, 555, and 1005 ms) and cue validity (D-G, D-U, D-O, S-U, and S-O) as within-subject factors. The ANOVA results revealed a significant main effect for SOA [$F(2,17) = 4.16$, $p < 0.05$], a significant main effect for cue validity [$F(4,17) = 67.02$, $p < 0.0001$], and a significant SOA x cue validity interaction [$F(8,17) = 18.43$, $p < 0.0001$]. With three levels of SOA and five levels of cue type, it is difficult to interpret these effects. Therefore, in order test the four predictions set forward in the introduction, we conducted the following tests:

---------- Insert Figure 5-2 about here ----------

(1) Did participants shift attention to a gazed-at location? To investigate whether our directed gaze cues produced shifts of attention to gazed-at locations, we conducted a separate ANOVA for directed gaze trials in which targets occurred either at gazed-at locations or at uncued locations. The within-subject factors were SOA (105, 555, and 1005 ms) and cue validity (D-G and D-U). The results of this ANOVA revealed that there was a

significant main effect for SOA [$F(2,17) = 27.24$, $p < 0.0001$], with RTs longer at 105 ms SOA than at 555 and at 1005 ms SOA, reflecting a standard foreperiod effect that we have observed in previous gaze studies (e.g., Friesen & Kingstone, 1998). There was also a significant main effect for cue validity [$F(1,17) = 5.02$, $p < 0.05$], with shorter RTs when the target occurred at a gazed-at location versus an uncued location. The SOA x cue validity interaction was not significant [$F(2,17) = 0.49$, $p > 0.60$], indicating that the magnitude of the facilitatory effect was constant across the three SOA durations.

(2) *Did the face onset produce IOR?* To test for the IOR effect apart from any gaze direction effects, we conducted an ANOVA on straight gaze trials, with SOA (105, 555, and 1005 ms) and cue validity (S-U and S-O) as within-subject factors. There was a main effect for SOA [$F(2,17) = 4.99$, $p < 0.02$], with RT increasing as SOA increased. There was also a main effect for cue validity [$F(1,17) = 71.31$, $p < 0.0001$], reflecting the IOR effect (i.e., longer RTs when the target occurred at the face onset location than when it occurred at an uncued location). And finally, there was a significant SOA x cue validity interaction [$F(2,17) = 18.89$, $p < 0.0001$], reflecting the fact that, as expected, IOR occurred at the two longer SOAs, but not at the short 105 ms SOA. At the 105 ms SOA, only 8 out of the 18 participants were slower on S-O trials than on S-U trials; but by 555 and 1005 ms SOA the number of participants who were slower on S-O trials had risen to 18 out of 18, and 16 out of 18, respectively. A planned comparison of S-U vs. S-O at the critical 555 ms SOA revealed that participants were significantly slower to respond to a target when it occurred at the location of the gaze cue onset than when it appeared at an uncued location [$t(17) = 7.72$, $p < 0.0001$].

(3) Did orienting to a gazed-at location and IOR occur in response to the same stimulus? To test our prediction that at the 555 ms SOA, IOR would occur at the face onset location in response to the same stimulus that produced facilitation at a gazed-at location, we compared directed gaze trials in which the target occurred at an uncued location with directed gaze trials in which the target occurred at the location of the gazing face onset (i.e., D-U vs. D-O trials) at 555 ms SOA. This test revealed that subjects were significantly slower to respond to a target if it occurred at the location of the gazing face onset than if it occurred at one of the uncued locations [$t\ (17) = 12.75$, $p < 0.0001$]. Thus, the same directed gaze stimulus that caused a shift of attention to a gazed-at location also produced IOR at the location in which it appeared.

(4) Did gaze direction affect the magnitude of IOR? Finally, to investigate whether our directed gaze cues had any influence on the IOR effect, we conducted a planned comparison of the two trial types on which IOR was observed at 555 ms SOA: directed gaze trials in which the target occurred at the onset location and straight gaze trials in which the target occurred at the onset location (i.e., D-O vs. S-O at 555 ms SOA). This test revealed that IOR did not vary significantly as a function of whether gaze was directed at another location [$t(17) = 0.54$, $p > 0.50$]. This indicates that at 555 ms SOA, the IOR effect at the sudden onset location was unaffected by the co-occurrence of orienting to a gazed-at location.

Discussion

In the present study, both reflexive orienting to gaze direction and inhibition of return (IOR) were observed. The nonpredictive gaze direction of a schematic face produced shorter RTs (and no IOR) for targets at a gazed-at location compared to targets at locations that were not gazed at, consistent with the findings of Driver et al. (1999), Friesen and Kingstone (1998), and

Langton and Bruce (1999). The IOR effect occurred at the two longer SOA intervals, where responses were much slower for targets occurring at the location of the abrupt face onset than for targets occurring at other locations. These two reflexive attentional phenomena, orienting to a gazed-at location and IOR to the location of an abrupt onset, exhibited different but overlapping time courses.

The key finding in the present study is that at the 555 ms SOA, reflexive attention to gaze and IOR occurred at the same SOA and at different locations in response to exactly the same stimulus. When gaze was directed at one of the three other locations and a target occurred at one of these locations, RT was shorter if the target occurred at the gazed-at location than if it occurred at a location that was not gazed-at (the gaze direction effect). And when gaze was directed at one of the three other locations and a target occurred at the location of the gazing face onset, RT was much longer (the IOR effect). Furthermore, the size of the IOR effect at the onset location was not affected by whether or not gaze was directing participants' attention to another location. Taken together, these results suggest that these two covert spatial orienting mechanisms are independent and can co-occur.[1]

There are several questions that could be raised concerning the findings of the present study. First, because the target offset on D-O and S-O trials occurred at a location very close to the cue onset, one might question whether the RT delay we observed reflects low-level perceptual masking rather than IOR. Alternatively, one might wonder if the target offset was simply hard to perceive because the target circle is seen as part of a general face gestalt. Both these low- and high-level masking accounts predict that the RT delay at the cue-onset location will be greatest at the shortest cue-target SOA. This prediction is not, however, supported by the data. There was no

RT delay at the cue-onset location at the short 105 ms cue-target SOA. Rather, RT delays occurred only at the longer cue-target intervals -- when IOR should affect performance.

Second, our position is that the orienting triggered by nonpredictive gaze direction is reflexive in nature because it occurs in response to uninformative gaze cues and it begins to emerge at short gaze-to-target SOA intervals. Nevertheless, it could be asked whether the gaze cuing effect observed in the present study truly represents a reflexive attentional shift. Perhaps, for example, the advantage for gazed-at target locations results from participants shifting attention endogenously to where the eyes are looking, either out of curiosity or because they do not believe the researcher's statement that the eyes are nonpredictive. We believe that our data are not consistent with this notion, because if participants were shifting attention volitionally, one would expect that the gaze effect would emerge slowly and increase as a function of SOA (Friesen, Ristic, & Kingstone, submitted; Jondides, 1981). In the present study however, a very different data pattern was observed, with the gaze effect present at the shortest SOA and remaining steady across all SOA durations. (Indeed, if anything the gaze effect was declining rather than increasing at the longest SOA.)

It is our position, moreover, that gaze-triggered orienting is reflexive not only in the sense that it occurs automatically in the absence of strategic incentive, but in the stronger sense that it can occur against the intent of the participant and that it can occur in the absence of awareness of the stimulus triggering the orienting response. Both of these properties have been observed with peripheral cues: sudden peripheral onsets can attract attention even when they predict that a target is likely to appear at another location (Posner, Cohen, & Rafal, 1982); and they can trigger orienting even when the observer is unaware of the cue's appearance (Danziger, Kingstone, & Rafal, 1998; McCormick, 1997). Recent evidence from gaze studies suggests that gaze-triggered orienting may also be reflexive in this stronger sense. For example, both Driver et al. (1999) and Friesen, Ristic, and Kingstone (submitted) found that participants oriented to a gazed-at location even when the gaze cues were counterpredictive of target location. And in a recent study with masked gaze cues, participants shifted attention to gazed-at locations even though they had not been aware that pupils had appeared in the eyes of a schematic face (Friesen, Kingstone, & Bischof, manuscript in preparation).

Finally, one could ask whether rather than reflecting co-occurring phenomena, our finding of both a gaze cuing effect and an IOR effect at the 555 ms SOA might have been produced by participants shifting attention to the gazed-at location on some trials and inhibiting the onset location on other trials. If this were the case, one would expect RTs to be more variable for 555 ms D-O trials (in which the directed gaze cue could conceivably produce one effect on some trials and the other effect on other trials) than for S-O trials (in which gaze was not directed at another location, so only the IOR effect could be expected to occur). To investigate this possibility, we examined the untrimmed data for a difference in variability between D-O and S-O trials at 555 ms SOA. The interparticipant means of each participant's mean standard deviation for D-O and S-O trials at 555 ms SOA were identical (both 120 ms), suggesting that responses on the two trial types were equally variable. As a second check, we also looked at individual subjects' RT distributions for D-O 555 ms SOA trials for each subject. A visual inspection of these distributions revealed no signs of bimodality. Thus, there is no evidence to suggest that our effects can be attributed to gaze-triggered orienting (but no IOR) occurring on some directed-gaze cue trials and IOR (but no gaze-triggered orienting) occurring on other directed-gaze trials. Alternatively, one could wonder whether at the 555 ms SOA gaze-triggered orienting (and not IOR) occurred for some participants, and IOR (and not gaze-triggered orienting) occurred for other participants. We tested for such a negative correlation, and found that there was none [Pearson's r = -0.06]. Moreover, only six of our eighteen subjects showed one effect but not the other at 555 ms SOA (five showed the IOR effect but not the gaze effect, and one showed the gaze effect but not the IOR effect), and when these six subjects were removed from the analyses both the gaze effect and the IOR effect remained significant [both p's < 0.0001].

Thus, we believe that the RT delay observed in the present study for targets occurring at the onset location does indeed reflect IOR, that the gaze effect observed does indeed reflect a reflexive attentional shift, and that the two phenomena co-occurred at the 555 ms SOA. To our knowledge, our finding that a reflexive shift of spatial attention to one location and spatial IOR at another location can co-occur has not been reported in the literature before. Traditionally, reflexive shifts of attention and IOR to a previously attended location have both been elicited by a peripheral onset cue. Facilitation, if it is observed, occurs early at the cued location; and inhibition appears later at the same cued location (Posner and Cohen, 1984). This "biphasic" response time pattern, coupled with evidence that both reflexive facilitation and inhibition are mediated by the superior colliculus (Rafal, Henik, & Smith, 1991; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988), suggests that a common attentional system, or a common set of subsystems, may support location-based facilitation and inhibition triggered by exogenous peripheral cues.[2]

The co-occurrence of a reflexive shift of attention to a gazed-at location and inhibition at the location of an abrupt peripheral onset observed in the present study strongly suggests that gaze direction engages a different reflexive attentional system or subsystem from that supporting inhibition to a peripheral onset location. This interpretation is consistent with convergent evidence suggesting that reflexive attention to gaze direction is supported by cortical pathways. Single cell recording studies with monkeys have revealed that there are cells in inferior temporal cortex (IT) responsive to faces and eyes (for a review, see Desimone, 1991), which project to cells in the superior temporal sulcus (STS) responsive to particular gaze directions (Campbell, Heywood, Cowey, Regard, & Landis, 1990; Perrett et al., 1985), which in turn share reciprocal connections with cells in the parietal cortex (Harries & Perrett, 1991). Given that eyes would have to be perceived as eyes before they could cause a reflexive attentional shift, and given that the parietal lobe is known play a major role in spatial attention, this cortical IT to STS to parietal pathway seems a likely network through which brain mechanisms specialized for gaze processing might trigger reflexive shifts of attention. There is also evidence from human studies that cortical areas play a major role in attention to gaze direction. In a recent behavioral study of split-brain patients, reflexive attention to gaze direction occurred only in the hemisphere specialized for face processing (Kingstone, Friesen, & Gazzaniga, 2000). Also recently, functional neuroimaging studies have found selective activation in temporal areas analogous to the monkey STS, as well as in parietal cortex, in response to gaze direction (Hoffman & Haxby, 2000; Wicker, Michel, Henaff, & Decety, 1998).

In sum, by producing reflexive attention to gaze concurrently with a phenomenon known to be mediated by the SC, the present study provides behavioral evidence that the mechanisms supporting reflexive attention to gaze direction are independent from the mechanisms supporting IOR. This agrees with the evidence indicating that subcortical mechanisms play a crucial role in attentional orienting to and inhibition of abrupt peripheral onset locations, and that cortical brain mechanisms are critical for orienting to gaze direction.

Endnotes

[1] Although we did not monitor subjects' eye movements in our experiment, we are confident that eye movements were not involved in producing our effects. First, it is well known that for simple detection tasks subjects will spontaneously avoid making eye movements to the target (Posner, 1980). Second, in the present experiment, all stimuli were within approximately 2° of fixation, making eye movements especially unlikely. And finally, if participants were making eye movements in response to the gaze cue, one would expect to see the gaze effect to vary as a function of SOA (i.e., be greater at the longest SOA than the shortest SOA); however, in the present experiment facilitation for gazed-at targets was constant across all SOAs (and, if anything, the gaze effect was smaller at the longest SOA than the shortest SOA).

[2] Although several recent studies have found evidence that reflexive orienting to sudden onset cues and IOR are separable and may be subserved by different mechanisms, it is important to note that this dissociation has been revealed for object-based IOR, in which an object is cued and then moved to a new location, rather for location-based IOR (e.g., Tipper et. al, 1997; Ro & Rafal 1999). The results of these studies suggest that there may be more than one type of IOR, with object-based IOR supported, at least in part, by cortical mechanisms. To our knowledge however, the weight of evidence concerning location-based IOR is consistent with the notion that it is subserved by subcortical mechanisms.

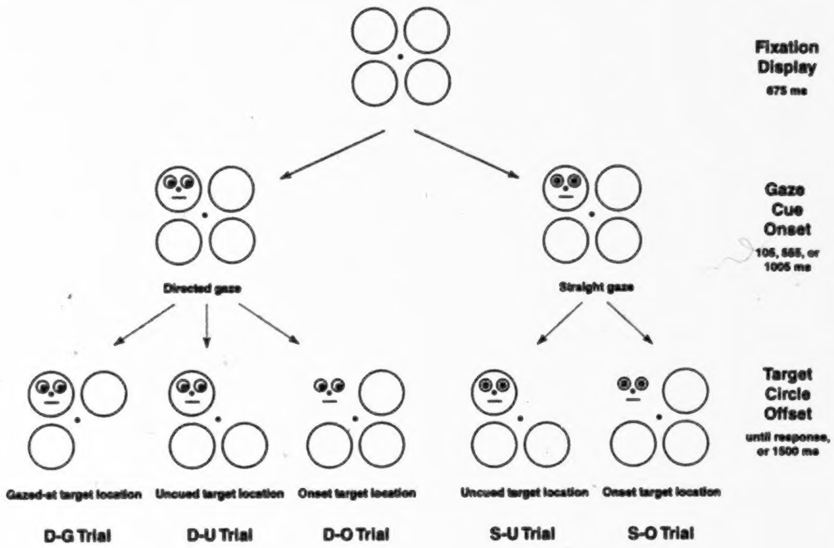
Fixation Display
675 ms
Gaze Cue Onset
105, 555, or 1005 ms
Target Circle Offset
until response, or 1500 ms
Directed gaze
Straight gaze
Gazed-at target location
Uncued target location
Onset target location
Uncued target location
Onset target location
D-G Trial
D-U Trial
D-O Trial
S-U Trial
S-O Trial

Figure 5-1. Illustration of the trial sequence for each of the five possible trial types. Each trial began with four circles surrounding a central fixation dot. A gazing face appeared with equal probability in one of the four circles. The face's gaze was either Directed at one of the other three location circles, or Straight ahead. The target event, which occurred 105, 555, or 1005 ms after the onset of the gaze cue, was the offset of one of the four location circles either at the Gazed-at location, at an Uncued location, or at the location of the Onset of the gazing face. Note that stimuli are not drawn to scale with respect to the surrounding white background.

Table 5-1. Mean Response Times, Standard Deviations, and Error Rates

	105 ms SOA			555 ms SOA			1005 ms SOA		
Trial Type	M	SD	%E	M	SD	% E	M	SD	% E
D-G	366.6	64	0.00	334.3	54	1.11	350.9	53	1.96
D-U	372.4	57	0.15	342.4	52	1.62	354.8	55	2.96
D-O	379.6	56	0.32	403.4	61	1.68	411.7	66	1.66
S-U	367.4	62	0.31	342.7	52	2.19	357.2	54	1.85
S-O	368.9	58	0.00	406.7	58	2.40	420.9	70	1.82

Mean Response Times (RT) in Milliseconds (ms), Standard Deviations (SD), and Error Rates (% E) for each type of trial at each stimulus onset asynchrony (SOA) interval. Error rates represent the percentage of target trials excluded from the analysis as anticipations (RTs < 100 ms) or timed-out trials (no response within 1500 ms).

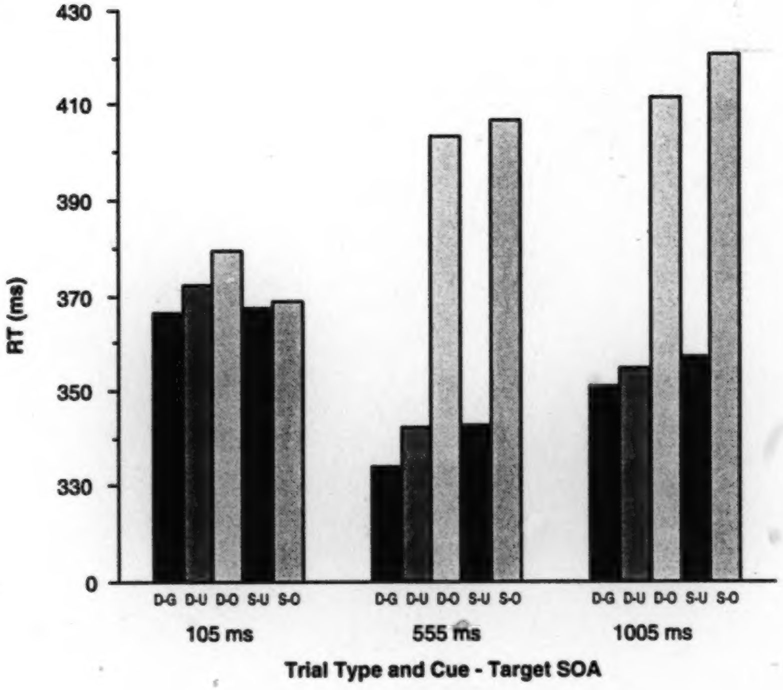

Figure 5-2. Mean response times (RT) in milliseconds (ms) as a function of trial type (D-G = gaze is Directed, target occurs at the Gazed-at location; D-U = gaze is Directed, target occurs at an Uncued location; D-O = gaze is Directed, target occurs at the location of the face Onset; S-U = gaze is Straight ahead, target occurs at an Uncued location; S-O = gaze is Straight ahead, target occurs at the location of the face Onset) and gaze cue-to-target stimulus onset asynchrony (SOA). See Figure 1 caption for an illustration of each of the five trial types. At 555 ms SOA, the gaze effect is D-G vs. D-U, and the IOR effect is: S-U vs. S-O.

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Chapter 6

Covert and overt orienting to eye gaze direction and the effects of fixation offset

Introduction

In recent years, several studies have reported that adults will shift attention in response to the gaze direction of a stimulus face presented at central fixation (Driver et al., 1999; Friesen & Kingstone, 1998; Friesen, Moore, & Kingstone, in preparation; Friesen, Ristic & Kingstone, submitted; Langton & Bruce, 1999). The attention shift triggered by gaze direction is thought to be reflexive in nature because it emerges rapidly and occurs in response to nonpredictive cues. Moreover, it seems to represent a unique type of orienting with a time course that is different from the time courses typically produced by exogenous cues and endogenous cues. Exogenous cues (such as nonpredictive peripheral abrupt onsets) tend to produce orienting that emerges rapidly but disappears shortly thereafter; and endogenous cues (such as predictive centrally-presented arrows) tend to produce orienting that is slow to emerge but persists for a relatively long time. Gaze-triggered orienting is like exogenous orienting in that it emerges within 100 milliseconds (ms) after cue presentation, but it is also like endogenous orienting in that a stimulus at central fixation triggers shifts of attention to a peripheral location that persists for as long as 600 - 700 ms.

In all of the gaze cuing studies reported to date, the orienting observed has been covert, because observers were always instructed to fixate the center of the stimulus display throughout the experimental trials and to make a manual response to a target without moving their eyes. To our knowledge, however, there is no published study that has examined overt orienting in response to gaze direction by having observers make eye movements to a target. Given the abundant evidence that overt and covert orienting are separable processes (Posner, 1978; Klein, Kingstone & Pontefract, 1992) it was important to determine whether or not the effects that gaze direction has on covert orienting apply to overt orienting.

Thus, one of the main objectives of the present study was to measure eye movements in both manual and eye movement response tasks. In Experiment 1, observers maintained fixation on a central face stimulus that gazed nonpredictively to the left, to the right, or straight ahead, and responded manually to a subsequently-appearing target. In Experiment 2, a different group of observers was tested under the same stimulus conditions. These subjects were instructed to begin each trial with their eyes on the face at central fixation, and to make an eye movement to the target when it appeared. In this way, covert and overt orienting in response to gaze direction could be compared.

A second objective of the present study was to investigate whether reflexive orienting to gaze direction involves subcortical mechanisms. The evidence to date suggests that in addition to producing unique behavioural effects, reflexive orienting to gaze direction may be subserved by different neural mechanisms from those subserving reflexive orienting to abrupt onsets in the periphery. Whereas subcortical mechanisms are thought to play a major role in reflexive orienting to abrupt peripheral onsets (Rafal, Henik, & Smith, 1991; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988), there are several lines of evidence suggesting that reflexive orienting to gaze direction relies heavily on cortical mechanisms.

In the nonhuman primate literature, single cell recording studies with monkeys have revealed that there are cells in inferior temporal cortex (IT) that respond selectively to faces and eyes (for a review, see Desimone, 1991), which project to cells in the superior temporal sulcus (STS) responsive to particular gaze directions, head orientations, and body orientations (Campbell, Heywood, Cowey, Regard, & Landis, 1990; Perrett et al., 1985). These cells, in turn, were shown in a combined neurophysiological and anatomical study to share reciprocal connections with cells in the parietal cortex (Harries & Perrett, 1991), which is known to play a major role in spatial attention.

There is also evidence from human studies that cortical areas play a major role in attention to gaze direction. Results from functional neuroimaging studies suggest that gaze and upright face processing are preferentially lateralized to the right hemisphere (Puce et al., 1998; Wicker, Michel, Henaff, & Decety, 1998), and also that gaze direction perception selectively activates temporal areas analogous to the monkey STS, as well as parietal cortex (Hoffman & Haxby 1999; Hooker et al., 2001; Wicker, Michel, Henaff, & Decety, 1998). Convergent with these findings, a recent behavioural study of split-brain patients found that reflexive attention to gaze direction occurred only in the hemisphere specialized for face processing (Kingstone, Friesen, & Gazzaniga, 2000).

In contrast, there is considerable evidence in the attentional literature indicating that the subcortical superior colliculus (SC) is involved both in reflexive orienting to abrupt peripheral onsets and in the associated inhibition of return (IOR) that subsequently occurs at the abrupt onset location. Moreover, the SC is also known to play a major role in the generation of eye movements towards attended locations (e.g., Dorris & Munoz, 1995; Munoz & Wurtz, 1992). It is not known whether the SC is involved in any way in gaze-triggered reflexive orienting; however, at least two findings suggest that it might not be. First, gaze direction cues have never produced inhibition of return (IOR) at the gazed-at location (Driver et al., 1999; Friesen &

Kingstone, 1998; Friesen & Kingstone, submitted; Friesen, Moore, & Kingstone, in preparation; Friesen, Ristic & Kingstone, submitted; Langton & Bruce, 1999). And second, orienting to a gazed-at location and IOR at an abrupt onset location appear to be independent and have been observed to co-occur (Friesen & Kingstone, submitted).

In order to explore whether the SC might be involved in reflexive orienting to gaze direction we introduced a manipulation known to engage and disengage the SC. In each experiment, on half of the trials the gazing face cue remained on the screen after target onset, and on the other half of the trials the face cue was extinguished at the time of target onset. It is well known that removing a stimulus from central fixation before or simultaneous with the presentation of a peripheral target can facilitate response time (RT) to make an eye movement to the target (Saslow, 1967; Ross & Ross, 1980; Ross & Ross, 1981). This effect is known as the fixation offset effect (FOE), or "gap" effect, and there is a wealth of evidence that it occurs because removing the fixation stimulus disinhibits the SC, thereby releasing the eye movement system (e.g., Dorris & Munoz, 1995, Munoz & Wurtz, 1992).

The question we were interested in here was: Does the SC play any role in reflexive orienting to gaze? Presumably gaze-triggered orienting is reflexive because of its potential to alert individuals living in social groups to events critical to survival, such as the approach of a predator. Thus, despite all of the evidence suggesting that orienting to gaze is primarily dependent on cortical processing, one might expect that the areas underlying this reflexive attentional phenomenon would be linked somehow to the subcortical attentional system that is thought to be specialized for rapid orienting, as well as to the eye movement system that makes it possible to quickly foveate items at attended locations for further processing.

We reasoned that two possible outcomes in eye movement response experiment (Experiment 2) would suggest that reflexive orienting to gaze direction involves the SC. First, we predicted that if shifting attention rapidly to where another individual is looking is linked to the eye movement system, we might observe a larger gaze cuing effect for eye movement responses than for manual responses If gaze direction cues automatically cause the programming of an eye movement, for example, then compared with manual responses, observers making eye movement responses should show greater response time (RT) benefits when they make an eye movement to a gazed-at target location (because the response has already been programmed) and greater costs when they make an eye movement to a nongazed-at target location (because they have to cancel the prepared eye movement and prepare an eye movement in the opposite direction).

A second idea was that deviated gaze might predisengage the eye movement system to facilitate rapid overt orienting (Taylor, Kingstone & Klein, 1998), and that this might be revealed as difference in the size of the FOE as a function of whether gaze is averted or straight ahead. We predicted that if deviated gaze predisengages the eye movement system, then there should be little or no fixation offset effect when the gaze cue was directed to the left or right (because the eye movement system would already have been released by the directed gaze cue before the offset of the fixation stimulus occurred), but that there would be an effect of fixation offset on straight-gaze trials.

In the following experiments, we were interested in investigating the effects of nonpredictive gaze direction at a cue-to-target stimulus onset asynchrony (SOA) of 500 milliseconds (ms), an SOA within the 100 - 700 ms range at which gaze-triggered orienting has been reliably observed in previous studies (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). We also included an equal number of trials at a longer SOA (1000 ms) so that on the 500 ms SOA trials in the eye movement experiment (Experiment 2), observers' expectancies about when a target would appear would not cause endogenous predisengagement of the eye movement system (Taylor, Kingstone & Klein, 1998). It should be noted that the 1000 ms SOA trials in the eye movement experiment (Experiment 2) are compromised by this opportunity for endogenous predisengagement, and that therefore only the 500 ms SOA trials are included in our analyses.

Experiment 1: Manual Responses

The main purpose of Experiment 1 was to establish baseline measures of covert orienting to gaze direction under the same experimental conditions that would be used to assess overt orienting to gaze in Experiment 2. Each trial began with the presentation of a schematic face with blank eyes in the center of the screen. Pupils then appeared in the eyes gazing nonpredictively to the left, to the right, or straight ahead. After either 500 or 1000 ms, a target appeared to the left or right of the face. The gazing face cue either disappeared at the time of target onset, or remained on the screen for the duration of the trial. Participants maintained central fixation throughout each trial, and made a speeded manual response to the appearance of the target.

Method

Participants

Participants were 10 psychology undergraduates who participated in the experiment for course credit. All participants reported that their vision was normal or corrected-to-normal (with contact lenses), and all were unaware of the purpose of the experiment.

Apparatus

Participants were seated in a dimly-lit room, and rested their chin and forehead on a desk-mounted headrest positioned 50 cm from the computer monitor, which was a 17" ADI MicroScan 5G. The researcher adjusted chair position and height, as well as headrest height, so that subjects' eyes were approximately aligned with the center of the monitor. The eye movement monitor was an Applied Science Laboratories EyeTrac 210. It was mounted on an Applied Science Laboratories headband, and took readings of horizontal movements of the left eye. The eye movement monitor had a resolution of 0.25°. Calibration of the eye movement monitor was accomplished by taking samples at three locations on the horizontal meridian of the screen: at center, 10° to the left of fixation, and 10° to the right of center. The stimulus used for calibration was a black plus sign measuring 0.8° high by 0.8° wide. Calibration was performed at the beginning of the experimental session and between test blocks. Participants pressed either the left or right button of a four-button box for eye movement monitor calibrations and block initiation. The left and right buttons on the box were also used to collect manual response times during the experiment. The monitor used for stimulus presentation, the button-box, and the eye-movement monitor were interfaced with an IBM-compatible 486/80 MHz computer that controlled and recorded events throughout the experiment. The computer and a second monitor were positioned outside of the testing room, in an adjacent room, to enable the experimenter to view a display of subjects' eye movements during experimental trials and calibrations. The researcher and participant were always able to communicate over an intercom.

Stimuli

The experimental stimuli, illustrated in Figure 6-1, were black line drawings on a white background, and consisted of a centrally presented schematic face and a peripherally presented target square. The outline of the face was an unfilled circle 8.0° in diameter. The nose in the center of the face, which served as the fixation point, was an unfilled circle 2.3° in diameter, positioned at the center of the screen. A 2.63° horizontal line positioned 1.5° below the nose represented the mouth. The outlines of the two eyes were unfilled circles 1.1° in diameter, the centers of which were positioned 0.9° above the horizontal meridian and 1.1° to the left or right of the vertical meridian. Black, filled-in circles appeared in the eye outlines and served as the gaze cue. These were 0.7° in diameter. They were centered vertically in the eye outlines, and were positioned so that they were either centered horizontally in the eye outlines (straight ahead gaze), or just touching the left or right sides of the eye outlines (left and right gaze). The target stimulus was a black filled-in square measuring 1.5° high by 1.5° wide. The center of the square was at the same horizontal position as the center of the eyes (i.e., 0.9 above the horizontal meridian), and was 10.5° to the left or right of the vertical meridian.

--------- Insert Figure 6-1 about here ---------

Design

The experiment consisted of 15 practice trials followed by 384 test trials, which were presented in eight blocks of 48 trials each. Seven subjects completed all eight blocks, but owing to time constraints, one subject completed only seven blocks and two subjects completed only six blocks.

Figure 6-1 illustrates the sequence of events on each trial. First, a face with blank eyes appeared in the center of the screen. After 1000 ms, pupils appeared in the eyes looking left, right, or straight ahead. Then after an interval of either 500 or 1000 ms, the target square appeared either to the left or the right of the face. The target (and the face, on overlap trials) remained on the screen until either a response was made or 800 ms had elapsed, whichever came first. The intertrial interval was 1000 ms.

There were three cue validity conditions: on cued trials, gaze direction was left or right, and the target appeared at the gazed-at location; on uncued trials, gaze direction was left or right, and the target appeared at the location opposite to where the eyes were looking; and on straight-gaze trials, gaze direction was straight ahead, and the target was equally likely to appear on either side of the face. There were also two fixation offset conditions: on simultaneous trials the face disappeared at the time of target onset; and on overlap trials the face remained on the screen after target onset. On each trial, gaze direction, target location, cue-target SOA, and fixation offset were selected randomly and equally within each block.

The participants' task was to maintain fixation in the center of the screen (i.e., at the location of the nose of the schematic face) at all times, and to press the left button on the button box when the target appeared on the left of the screen, and the right button when the target appeared on the right.

Eye movements were sampled at a rate of 1 sample/ms, beginning from 100 ms before the pupils' onset and continuing until the target offset. RT was calculated as the time from target onset to the time a button press response was recorded.

Procedure

At the beginning of the experiment, participants were shown the eye movement monitor and headgear, and were told that the researcher would ensure that they were in a comfortable and stable position before beginning the experiment, because it was very important that they not change positions or move their heads during the experimental blocks. They were also told that if at any time they were uncomfortable, they should inform the researcher via the intercom. Before positioning participants in front of the monitor and mounting the eye movement monitor, the researcher explained the experimental procedure.

Participants were told that between blocks, the researcher would perform eye movement monitor calibrations by having them fixate on a series of crosses on the screen. They were also told that on each trial, a drawing of a face with blank eyes would appear in the center of the screen, and that it was important that they fixate their eyes on the nose in the center of the face. Subjects were told that after the appearance of the face, pupils would appear in the eyes looking either left, right, or straight ahead, and that after that, their target (a black square) would appear either to the left or right of the face. They were also told that on half of the trials the face would disappear when the target appeared, and that on the other half of the trials, the face would remain on the screen after the target appeared. Participants were informed that the direction in which the eyes looked was not in any way predictive of where the target would appear or whether the face would disappear at the time of target onset.

Participants were instructed to maintain fixation at the location of the nose of the schematic face at all times (whether the face was present on the screen or not) and to press the left button on the centrally-positioned button box with their left index finger when the target appeared on the left of the screen, and the right button with their right index finger when the target appeared on the right. Participants were asked to respond to the target as quickly and accurately as possible, and were also told to keep their heads as still as possible during the experimental blocks, and to blink between, rather than during, the trials.

Participants were informed that there would be one block of practice trials followed by eight blocks of test trials. They were encouraged rest their eyes between the blocks and then push a button when they were ready to recalibrate for the next block. They were also told that they would be offered an opportunity to move back from the headrest for a short break halfway through the experiment, and they were offered an opportunity to ask questions about the procedure before the experiment began.

Results

Anticipations (manual responses occurring less than 80 ms after target onset), incorrect button presses, and timed-out trials were coded as manual response errors and were excluded from the analysis. Each of these types of error accounted for less than 1.1% of the data, and thus were not analyzed further. Of the remaining correct manual response trials, 8.28% were trials on which blinks or eye movements greater than 2.0° were recorded; these were excluded from the analysis as eye movement errors.

Mean RTs for correct responses are presented in Table 6-1. An ANOVA was conducted on mean RTs for 500 ms SOA trials (which are illustrated in Figure 6-2), with fixation offset (simultaneous and overlap) and cue validity (cued, uncued, and straight-gaze) as within-subject factors. The main effect for fixation offset was not significant [F (1, 9) = 0.33, p > .55], but there was a significant main effect for cue validity [F (2, 9) = 4.00, p < .04]. The fixation offset x cue validity interaction did not approach significance [F = 0.71, p > 0.50]. Planned comparisons of cued versus uncued trials for each fixation offset condition revealed that there was a reliable advantage for targets appearing at the gazed-at location on both simultaneous and overlap trials [both t's > 3.00, both p's < 0.01].

--------- Insert Table 6-1 and Figure 6-2 about here ---------

Discussion

The results of Experiment 1 include only trials on which no eye movement occurred, and therefore constitute a profile of purely covert orienting in response to nonpredictive gaze direction cues. Our results confirm that the RT benefits for gazed-at target locations observed in previous studies cannot be attributed to observers' making eye movements. The fact that responses were equivalent in the simultaneous and overlap conditions (i.e., that there was no FOE) was expected, given that: (1) the FOE is typically observed only when observers execute eye movements into the periphery (Kingstone & Klein, 1993); and (2) the face stimulus in the Langton and Bruce (1999) study disappeared at the time of target onset, and yet the gaze cuing effect observed in that study was consistent with the effect observed in studies in which the gazing face cue remained on the screen (Driver et al., 1999; Friesen & Kingstone, 1998).

Experiment 2: Eye Movement Responses

The purpose of Experiment 2 was to investigate the effects of nonpredictive gaze on overt attentional orienting. In this experiment we presented a different group of observers with exactly the same stimuli and sequence of events as we employed in Experiment 1. The only difference was that instead of having participants maintain central fixation and respond manually to the appearance of the target, we now had participants make an eye movement to the target when it appeared on the screen.

As discussed in the introduction, we hypothesized two outcomes that might be observed if the SC is involved in reflexive orienting to gaze direction: (1) that the gaze effects would be larger for eye movement responses than for manual responses, because directed gaze causes the preparation of an eye movement; and (2) that the FOE would differ as a function of whether gaze was deviated or straight ahead, because deviated gaze disengages the eye movement system from the fixation stimulus before fixation offset occurs.

Method

Participants

Participants were 19 undergraduate psychology students who participated in the experiment for course credit. All subjects reported that their vision was normal or corrected-to-normal (with contact lenses), and all were unaware of the purpose of the experiment. None had participated in Experiment 1.

Apparatus and Stimuli

Apparatus and Stimuli were identical to those described in Experiment 1, with the exception that participants pressed a thumb-switch for eye movement monitor calibrations and block initiation, and that no buttons were used during experimental blocks.

Design

As in Experiment 1, there were 15 practice trials followed by 384 test trials presented in eight blocks of 48 trials each. Owing to time constraints, three of the 19 subjects completed only seven of the eight blocks.

The design was exactly the same as in Experiment 1, with the following exceptions: (1) the participants' task was to make an eye movement to the target instead of responding to the appearance of the target with a button press; (2) the target (and the face, on overlap trials) remained on the screen either until 250 ms after an eye movement was initiated or until 800 ms had elapsed, whichever came first; and (3) RT was calculated as the time from target onset to the initiation of a saccadic response.

Procedure

The procedure was identical to that in Experiment 1, with the exception that participants were instructed fixate the nose of the stimulus face at the beginning of each trial, to make an eye movement to the target square when it appeared, and then to move their eyes back to the center of the screen in order to be ready for the next trial.

Results

Anticipations (eye movements occurring less than 80 ms after target onset), blinks, timed-out trials (no response), eye movements in the wrong direction, and eye movements in the right direction that were less than 5.0° were coded as errors and excluded from the analysis. Anticipations accounted for 3.72% of the data, and blinks accounted for 5.24%. Timed-out trials and eye movements < 5° in the right direction each accounted for less than 1% of the data, and were not analyzed further. There were no eye movements in the wrong direction.

Mean RTs for correct responses are presented in Table 6-2. An ANOVA was conducted on mean RTs for 500 ms SOA trials (which are illustrated in Figure 6-3), with fixation offset (simultaneous and overlap) and cue validity (cued, uncued, and straight-gaze) as within-subject factors. There was a significant main effect for fixation offset (the FOE) with RT faster on simultaneous trials than on overlap trials [F (1, 18) = 56.26, $p < 0.0001$], and there was also a main effect for cue validity [F (2, 18) = 10.18, $p <0.0005$]. Importantly, the fixation offset x cue validity interaction was not significant [$F = 1.76$, $p > 0.18$], indicating that the offset effect was equivalent for cued, uncued and straight-ahead gaze conditions. Planned comparisons of cued versus uncued trials for each fixation offset condition revealed that there was a reliable advantage for targets appearing at the gazed-at location on overlap trials [$t = 2.89$, $p < 0.01$], but not on simultaneous trials [$t = 0.40$, $p > 0.65$].

--------- Insert Table 6-2 and Figure 6-3 about here ---------

Discussion

In Experiment 2, eye movement RT data revealed that observers shifted attention reflexively in response to nonpredictive gaze direction cues. However, the facilitation observed for gazed-at target locations occurred only in the overlap condition, and this overt orienting effect was less than half the size of the covert orienting effect observed for manual responses (uncued minus cued RT at 500 ms SOA on overlap trials was 27 ms in Experiment 1, and 12 ms in Experiment 2).

We had hypothesized that if the SC is involved in reflexive orienting to gaze direction, we might observe one of two possible outcomes. One prediction was that if gaze direction automatically causes the preparation of an eye movement, gaze cuing effects should be greater for eye movement responses than for manual responses. If a response has already been prepared at the time of target onset, this should increase RT benefits on cued trials, and it should also increase RT costs on uncued trials. Clearly, the gaze cuing effect was not larger in Experiment 2 than in Experiment 1, and therefore our results indicate that gaze direction does not trigger saccade preparation.

The second prediction was that the perception of deviated gaze might predisengage the eye movement system so that reflexively attended gazed-at locations could be quickly foveated. If the perception of deviated gaze causes the release of the eye movement system, then in the present experiment we would expect to see little or no FOE for left and right gaze cues because the eye movement system would already have been released by the gaze cue before the time of fixation offset, but we would expect to see the FOE with straight-gaze cues. In other words, the FOE would vary as a function of whether gaze was deviated or straight ahead. Our results revealed that although there was a significant FOE for eye movement responses, the FOE was additive across gaze cue conditions.

Taken together, our findings that deviated gaze does not trigger the preparation of an eye movement and that deviated gaze does not disengage the eye movement system indicate that the SC may not be involved in reflexive attention to gaze at all.

Finally, it should be noted that with eye movement responses, no gaze cuing effect was observed when the fixation face was extinguished at the time of target onset. This result was not necessarily expected, since turning off the fixation face did not affect gaze-triggered covert orienting in Experiment 1. The results of Experiment 2 do not allow us to say why there was no gaze cuing effect in the simultaneous condition. The removal of the fixation stimulus seems to have simply undercut any attentional effects of gaze direction. The most likely explanation is that the FOE for eye movements is a rapid, low-level effect that allows for an overt attentional shift to the peripheral target before gaze direction has had enough time exert its influence on spatial attention.

General Discussion

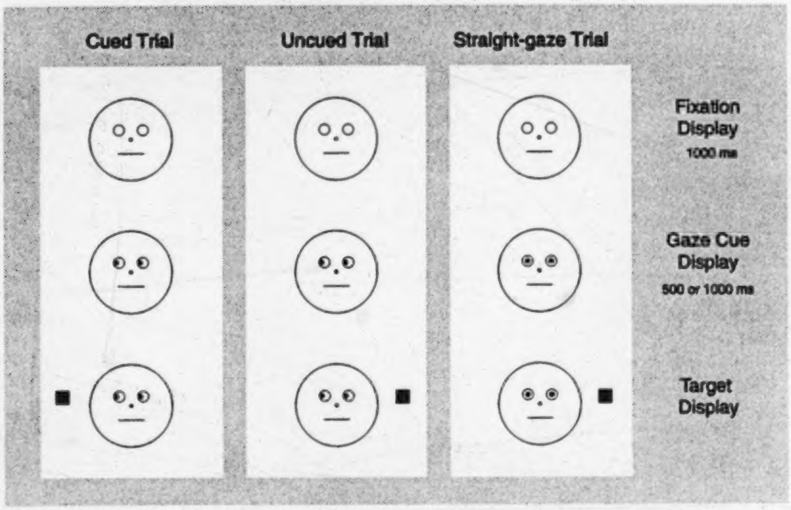
In the present study, we investigated covert and overt orienting in response to nonpredictive gaze direction cues under formal eye monitoring conditions. Additionally, we sought to determine whether the superior colliculus (SC) is involved in gaze-triggered reflexive orienting by extinguishing the central fixation stimulus on half the trials, a manipulation known to disengage the SC and thereby release the oculomotor system.

In Experiment 1, participants fixated a schematic face at central fixation throughout each trial and made manual responses to the appearance of a peripheral target. Response time was facilitated for targets appearing at a gazed-at location, regardless of whether the fixation face disappeared at the time of target onset or remained on the screen throughout the trial.

Experiment 2 was exactly the same as Experiment 1, except that instead of manual responses, participants made eye movement responses to the appearance of the target. Reflexive overt orienting in response to gaze direction was observed, but only when the fixation stimulus remained on the screen after target onset. This orienting effect was not larger than the covert orienting observed in Experiment 1, as it should have been if reflexive orienting to gaze caused the preparation of a saccade to the gazed-at location. A significant FOE was also observed, but it did not vary as a function of whether gaze was diverted or straight ahead, as it should have done if gaze direction predisengages the eye movement system. These findings suggest that gaze-triggered orienting does not involve the SC.

In sum, the results of the present study indicate that gaze direction triggers reflexive orienting without saccade preparation, that the effects of this orienting can be seen whether or not eye movements are made, and that gaze direction cues do not disinhibit the SC.

Overlap Condition


Cued Trial
Uncued Trial
Straight-gaze Trial
Fixation Display
1000 ms
Gaze Cue Display
500 or 1000 ms
Target Display

Simultaneous Condition

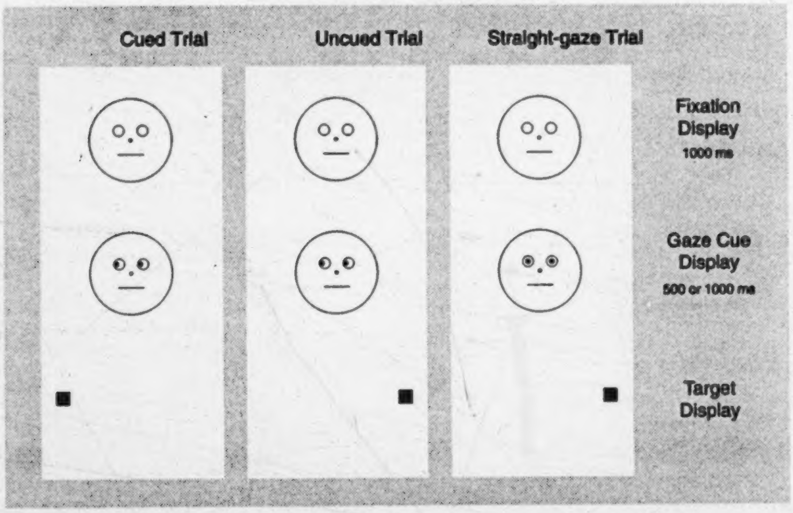

Cued Trial
Uncued Trial
Straight-gaze Trial
Fixation Display
1000 ms
Gaze Cue Display
500 or 1000 ms
Target Display

Figure 6-1. Illustration of stimuli and examples of cued, uncued, and straight-gaze trial sequences for the simultaneous and overlap conditions in both Experiment 1 and Experiment 2. Each trial began with a fixation display of a face with blank eyes. After 1000 ms, pupils appeared in the eyes looking left, right, or straight ahead (the gaze cue). Then, after 500 or 1000 ms a square (the target) appeared to the left or the right of the face. In the simultaneous condition the gazing face stimulus disappeared at the time of target onset. In the overlap condition, the face cue remained on the screen until a response was made.

Table 6-1. Mean Response Times (RT) and Standard Deviations (SD) for Experiment 1

Fixation Offset Condition	SOA	Cue Validity	RT	SD
Simultaneous	500 ms	cued	397	59
		uncued	430	72
		straight-gaze	413	61
	1000 ms	cued	370	56
		uncued	392	71
		straight-gaze	391	74
Overlap	500 ms	cued	406	58
		uncued	427	61
		straight-gaze	418	48
	1000 ms	cued	376	61
		uncued	391	60
		straight-gaze	387	54

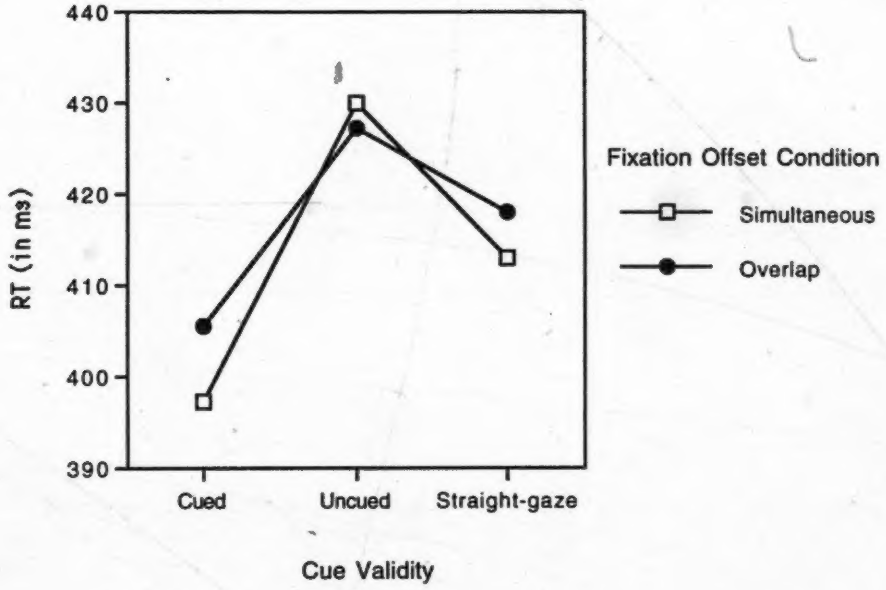


Figure 6-2. Mean response times (RT) in milliseconds (ms) as a function of gaze cue validity and fixation offset condition for 500 ms SOA trials in Experiment 1.

Table 6-2. Mean Response Times (RT) and Standard Deviations (SD) for Experiment 2

Fixation Offset Condition	SOA	Cue Validity	RT	SD
Simultaneous	500 ms	cued	211	23
		uncued	213	26
		straight-gaze	216	23
	1000 ms	cued	196	20
		uncued	196	23
		straight-gaze	195	22
Overlap	500 ms	cued	239	38
		uncued	251	33
		straight-gaze	252	40
	1000 ms	cued	226	38
		uncued	222	45
		straight-gaze	220	42

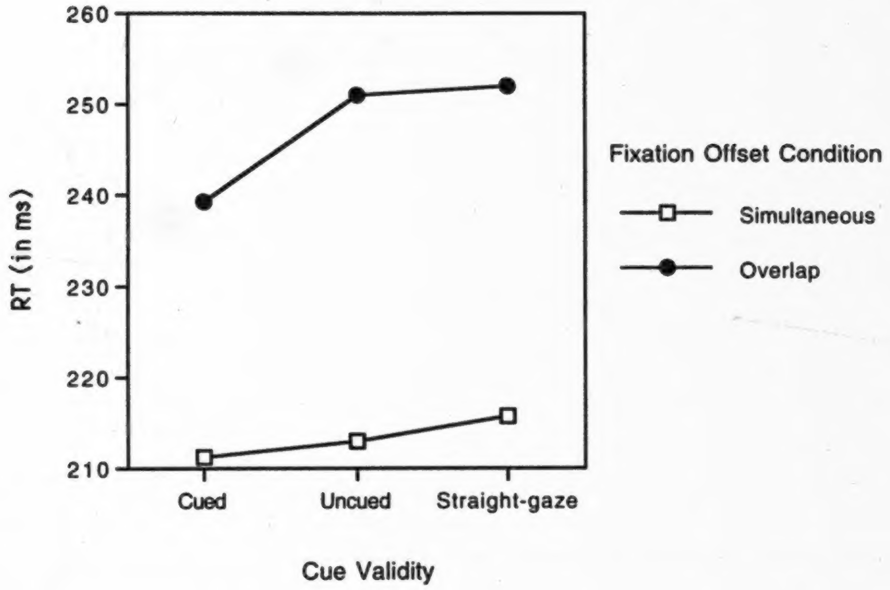


Figure 6-3. Mean response times (RT) in milliseconds (ms) as a function of gaze cue validity and fixation offset condition for 500 ms SOA trials in Experiment 2.

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Chapter 7

General Discussion

The overall goals of this dissertation research were to explore the nature of the attentional orienting triggered by perceived gaze direction, to characterize its time course, to explore its relationship with other known types of orienting, and to make inferences about how it may be carried out in the brain. In the five studies (seven experiments) reported in this thesis, attentional cuing methods were used to investigate the effects of gaze direction. Previous attentional studies have produced evidence for two types of orienting: exogenous (reflexive) orienting to a sudden onset in the periphery; and endogenous (volitional) orienting to a location where a target is expected to appear. The studies presented here have produced several lines of evidence that gaze-triggered attention shifts might represent a third, distinct type of orienting.

One line of evidence is the finding that nonpredictive gaze direction cues produce a unique response time (RT) pattern. In the studies reported in the current work, gaze cues produced facilitation at the cued location that emerged early and persisted for a long time. In contrast, exogenous orienting to nonpredictive peripheral abrupt onset cues (such as the sudden brightening of a box on the left or right side of the screen) typically produces early but short-lived facilitation at the cued location; and endogenous orienting in response to predictive central directional cues (such as an arrow that indicates where a target is likely to appear) typically produces facilitation that is slower to emerge, but that persists for a relatively long time.

The results of the behavioural studies presented in the current work suggest that the attentional shift produced by gaze is reflexive in nature, because: (1) it occurs rapidly, at cue-target SOAs (stimulus onset asynchronies) as short as 100 milliseconds (ms) (Chapters 2, 3, 4, and 5); it occurs even when observers know that the gaze cue is not predictive of where a response target will appear (Chapters 2, 3, 5, and 6); and (3) it occurs even when the gaze cue is *counterpredictive* of where a target will appear (Chapter 4). However, the results of these studies also suggest that there are several qualitative differences between reflexive gaze-triggered orienting and the reflexive orienting that has been studied extensively with nonsocial cues. One important difference is that gaze direction triggers a reflexive shift of attention from central fixation to a location in the periphery. In previous studies of reflexive attention, the cue was presented in the periphery at a potential target location. Thus, the location of the cue was always bound to the location of a potential target, such that attention was captured reflexively by an event at the cued location rather than being sent from the location of the cue to a different location as it is in the gaze studies. A second important difference is that unlike the peripheral abrupt onset cues that trigger reflexive orienting, gaze direction cues do not give rise to inhibition of return (IOR). Previous studies have indicated that when attention is shifted reflexively to a peripheral location, the facilitation observed for targets appearing at the cued location is later followed by inhibition at that location. This IOR effect is thought to reflect a bias for novelty that helps to ensure that previously attended locations are not needlessly reinspected. However, the present research with gaze direction cues indicates that IOR does not necessarily follow a reflexive shift of spatial attention.

Yet another line of evidence that gaze direction produces a unique type of orienting is that the orienting triggered by gaze direction appears to be separable from, and independent of, both endogenous and exogenous attentional processes. In one study, when observers were presented with counterpredictive gaze cues, RT was facilitated for targets appearing at the likely (not gazed-at) target location at 600 ms SOA, and RT was *also* facilitated for targets appearing at the gazed-at (but unlikely) target location (Chapter 4). This result provides strong evidence that gaze-triggered orienting and volitional orienting are two distinct processes, and that they operate independently of one another. And in another study, when observers were presented with a gazing face that served both as a nonpredictive gaze cue and as a nonpredictive abrupt onset cue, both facilitation for gazed-at target locations and IOR at the location of the abrupt onset cue were observed at 555 ms SOA (Chapter 5). This indicates that attention to gaze direction occurs independently of the attentional system that governs exogenous attentional responses to abrupt onsets.

Finally, a study in which eye movements were measured provided the first demonstration that reflexive gaze-triggered orienting can occur overtly as well as covertly, and revealed that attentional orienting to gaze does not seem to be linked to the oculomotor system (Chapter 6). For eye movement responses, disinhibiting the subcortical superior colliculus (SC) by extinguishing the gazing face at central fixation caused a fixation offset effect (FOE), but this effect was not modulated by the nature of the gaze cue. The results of this study provided new evidence that unlike reflexive orienting to abrupt peripheral onsets, orienting to gaze direction does not seem to involve the SC, and are consistent with the evidence accumulated to date suggesting that gaze-triggered orienting is subserved primarily by cortical brain pathways.

The discovery that gaze direction triggers a unique type of reflexive orienting presents exciting challenges for future research. Although the findings reported in this dissertation indicate that gaze-triggered orienting is distinct from both traditionally-studied exogenous orienting and traditionally-studied endogenous orienting, it is not currently known whether gaze-triggered orienting involves mechanisms or stages of processing that overlap with endogenous and exogenous attentional control. Additionally, the relationship between orienting in response to gaze and orienting in response to directional cues that are not biologically relevant is not known. In the years to come, results from a diversity of research approaches such as functional neuroimaging and behavioural studies with normal adults, neuropsychological patients, and infants will likely converge to improve our understanding of attentional orienting in response to gaze direction and other social attention cues, and of how this orienting is carried out by attentional networks in the brain.